THE PLIO-PLEISTOCENE TOKAI GROUP AND THE TECTONIC DEVELOPMENT AROUND ISE BAY OF CENTRAL JAPAN SINCE PLIOCENE(Dissertation_全文)

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論文内容の要旨

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（論文題目）

The Plio—Pleistocene Tokai Group and the Tectonic Development around Ise Bay of Central Japan since Pliocene.

（鮮新・更新統東海層群と鮮新世以降の伊勢湾周辺地域における構造発達史）

（論文内容の要旨）

東海層群は、地質時代の第三紀末期である鮮新世から第四紀の更新世の初頭にかけて、現在の知多半島、濃尾平野、伊勢地方など、伊勢湾とその周辺の地域に堆積した淡水成の地層群を一括したものである。以前は、知多半島のものは常滑層群、濃尾平野のものは矢田川累層、伊勢地方のものは奄芸層群とよばれ、日本におけるこの時期の陸成層として標準的な地層とみなされ、多くの研究者によって様々な立場から研究が進められてきた。

主論文の内容は、大別して三つの部分からなりたっている。

最初のものは、東海層群の層序に関するものであり、伊勢湾西部の北伊勢地方に分布するこの地層群（奄芸層群）を対象として、綿密な野外調査によって層序を確かめ、岩相層序と火山灰層序に生層序、古地磁気層序およびフイッション・トラック年代による分析結果を総合し、詳細な年代層序のスケールを確立した。すなわち、東海層群は6累層に区分され、主要

な１３枚の火山灰層の追跡によって、岩相の側方変化の時間面に対する関係をあきらかにしている。また、その結果として、この地域の東海層群は約3 Ma から1.2 Ma にわたることがわかった。

第二の部分は、古地理的変遷に関しての研究をまとめたものである。北伊勢地方で確立した東海層群の層序区分を伊勢湾周辺の東海層群全体に及ぼし、時間的経過とともにこの地域の古地理がどのように変化したかを分析したものといえる。すなわち、大きく6.0 Ma から3.0 Ma にかけてのステージⅠと、それ以後、1.2 Ma に至るステージⅡとに分け、後者はさらに細かく6つのサブステージに分けている。ステージⅠにおいては、知多半島と南伊勢を結ぶはんらん原の地域が次第に静水域となり、東海湖とよばれる大きな湖沼地帯が出現したことを示している。この間、この湖は少しずつ北へ移動して行くが、約3.0 Ma 前後に大きな転換期を迎え、北方へ大きく移動するとともに西方へ移る要素が加わる。この時期からをステージⅡとして区分するが、それはさらに6つのサブステージに分けられ、湖の西方移動とともに、周辺山地の急激な隆起上昇とともに著しい堆積作用によって、約1.2 Ma ころに東海湖は消滅したとされる。このような東海湖の古地理的変遷を、申請者は構造運動と関連づけて説明しており、3.0 Ma をはさんで、それまでの南北圧縮の応力場に、あらたに東西圧縮の応力が付加されるようになったことによるとしている。

第三の部分は、第二瀬戸内区全体の構造運動のパターンについての討論である。この地質区には、東から西へ、東海湖、古琵琶湖、古大阪湾のような各堆積盆の配列が見られるが、それぞれの堆積物からの構造発達の比較を行ったものである。それによると、各堆積盆は、いずれもその初期に南部沈降域をもち、それが北方へ移動し、さらに北西ないし西へ移動するという共通のパターンが見られる。しかしながら、東方地域から西方地域へ行くにつれて、このような沈降域の移動の時期はおそいという時間的ズレがあることを発見している。しかも、これら各堆積盆の構造発達におい

て、 3.0 Ma 、 1.2 Maという時期はそれぞれ意味のある時期であることを指摘した。

以上のように、本論文においては、東海層群を綿密な野外調査により詳細な層序をたて、古地理的な変遷過程を検討することにより、東海湖の概念を明確にした。また、古大阪湾、古琵琶湖、東海湖をあわせた第二瀬戸内区の堆積作用と構造を統一的にとらえ、時間のスケールを入れることによって、中部地方から近畿地方にかけての鮮新世以降の構造発達史を編むことに成功した。

主論文

THE PLIO-PLEISTOCENE TOKAI GROUP AND THE TECTONIC DEVELOPMENT AROUND ISE BAY OF CENTRAL JAPAN SINCE PLIOCENE

by

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CONTENTS

ABSTRACT

The Tokai Group, one of the representative nonmarine Plio-Pleistocene sequences in Japan, is distributed around Ise Bay in southern part of central Japan. In this paper, the litho- and tephrostratigraphy of the Group in central and northern area(Hokuse area) on the west coast of Ise Bay are first described precisely. From the results of studies of biostratigraphy (plant remains and fossil mammals), paleomagnetism and fission track ages, those sediments are estimated to range from about 3.0 m.y. B.P. to about 1.2 m.y. B.P., in other words, from the Kaena event of the Gauss Normal Polarity Epoch to the early Matuyama Reversed Polarity Epoch.

The correlation among the sediments of the Tokai Group distributed in various localities like as Hokuse, Nanse(southern area on the west coast of Ise Bay), Nagoya and the Chita Peninsula, was carried out. As a conclusion, the geohistory of the sedimentary basin of Lake Tokai is divided into two stages, Stage I (about 6.0 m.y. B.P. to 3.0 m.y. B.P.) and Stage II (about 3.0 m.y. B.P. to 1.2 m.y. B.P.).

In connection with this, the paleogeography of Lake Tokai and its mode of transition are explained. Following up to wide distribution of the early alluvial plains of about 6.0 m.y. B.P., a large water body appeared in the southern area of the basin in Stage I. At about 3.0 m.y. B.P., the northwestward shifting of the basin came to induce an appearance of water body in the northern area, and it was the beginning of Stage II.

In the last of Stage II, a large amount of gravel was supplied from the Suzuka Mountain area, and those materials filled up whole of the sedimentary basin nearly completely. In such a way, Lake Tokai became to extinct at last at about 1.2 m.y. B.P. In relation to basin transition, the mode of the tectonism may be interpreted as the results of the interaction between the upheaving of the southern area under the tectonic stress in N-S direction and the tilting of the Chubu Block influenced by the stress state in E-W direction.

Comparison of the geohistory was made for the Tokai, Kobiwako and Osaka Groups which are all allied sequences in the Second Setouchi Sedimentary Basin. Consequently, it becomes clear that the division between Stage I and Stage II of Lake Tokai (about 3.0 m.y. B.P.) is fairly coincidental with the division between Older I and Older II stages of Paleo-lake Biwa, and moreover, with the initial stage of Paleo-lake Osaka. Therefore, this phase of 3.0 m.y. B.P. should be regarded to play the important role in the geohistory of the Second Setouchi Inland Depression. It is also important that the extinction of Lake Tokai at about 1.2 m.y. B.P. was able to be correlated with the confines between Older and Actual stages of Paleo-lake Biwa, and with the first marine transgression in the area around Osaka Bay. Furthermore, a similar pattern of the basin migration was recognized in both Lake Tokai and Paleo-lake Biwa, but it should be noted that the northwestward migration of Paleo-lake Biwa on a large scale occurred at a later date to be compared with that of Lake Tokai. The causes of the migration of two sedimentary basins were commonly explained as mutual interaction between the upheaving of the southern area and the tilting movement of the eastern area.

I. INTRODUCTION

Three sedimentary basins, Lake Tokai, Paleo-lake Biwa and Paleo-lake (bay) Osaka, are arranged latitudinaly in southwest Japan from east to west in the eastern part of Second Setouchi Inland Depression of Ikebe (1956). All of those basins are filled with the Plio-Pleistocene sequences, and they are named the Tokai, Kobiwako and Osaka Groups, respectively (Fig. 1). Since 1977, the author has engaged in the stratigraphical studies on the Tokai Group on the west coast of Ise Bay, and confirmed the relation between litho- and tephrostratigraphy, and its chronological situation by the methods of paleomagnetism and fission track dating. Based on these studies, the author has also tried to correlate the sediments of that group which are distributed throughout the areas around Ise Bay. From those results, it becomes clear that the geohistory of Lake Tokai can be divided into two stages (Stage I and Stage II) with the boundary at about 3.0 m.y. B.P. Furthermore, the paleogeography of Lake Tokai since Pliocene will be explained on the basis of lithofacies and sedimentological data (lithologic proportion, gravel composition and paleocurrent).

It is inferred that the temporal changes of regional tectonic stress state reflected closely the mode of basin transition on the basis of paleogeographic studies. Accordingly, this article deals with the transition of sedimentary basin of Lake Tokai and the tectonism in the eastern part of the Setouchi Geologic Province since the Pliocene.

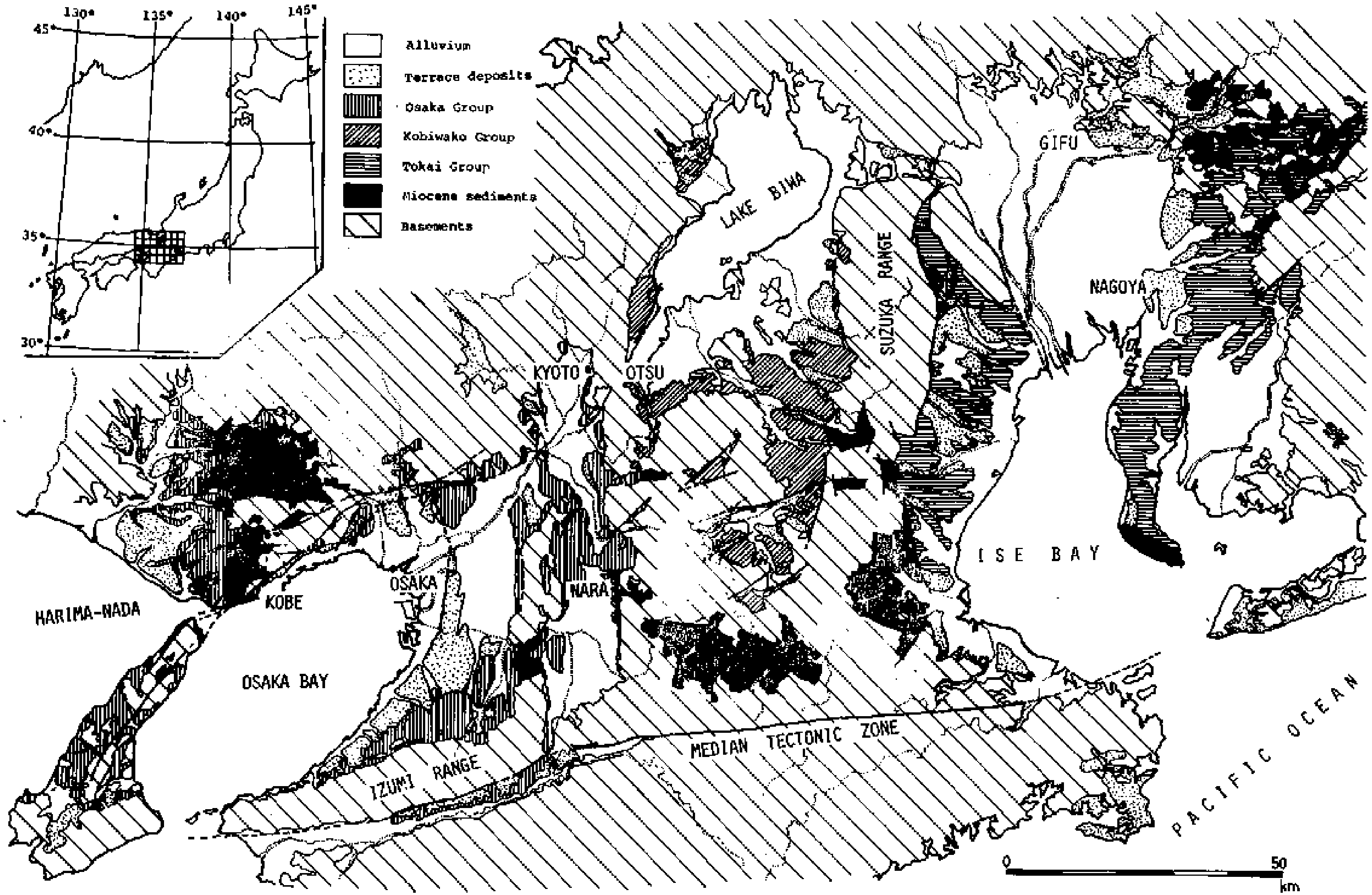


Fig. 1. Distribution of the Plio-Pleistocene series in the eastern Setouchi Geologic Province.

Huzita (1962) distiguished two types of structural trend, that is, the older latitudinal trend and the younger meridional trend in the Setouchi Province since the Pliocene. Recently, he has proposed an idea that the Quaternary tectonics of the Japanese Islands can be explained by two types of tectonic zone (parallel to the Nankai Trough and Japan Trench) (Huzita, 1980). In addition, the regional stress state of the Japanese Islands in the present and Late Quaternary Period has been deduced from the distribution of active faults, earthquake mechanism and remeasurements of triangulation points.

In this way, the distribution pattern of the regional horizontal principal stress has been determined (Matsuda et al., 1978). Moreover, the informations on the tectonic stress state since Miocene have been much accumulated (Nakamura, 1977: Takeuchi, 1980: Kobayashi, 1979). Taking these results into considerations, change of the pattern of the tectonic stress state in the eastern part of the Setouchi Province since Pliocene will be proposed here in relation to the process of the paleogeographical transition of those three basins, Lake Tokai, Paleo-lake Biwa and Paleo-lake(bay) Osaka.

II. GEOLOGY OF THE TOKAI GROUP IN NORTHERN ISE AREA

A. HISTORICAL REVIEW

In the historical review of the studies on the Plio-Pleistocene sediments in Kinki and Tokai districts, it should be described that Ikebe(1933, 1934) described tephrostratigraphically the stratigraphy of the Kobiwako Group first, and Huzita et al.(1951) demonstrated the alternations of marine and nonmarine facies and intercalations of volcanic ash layers of the Osaka Group. Besides them, many investigators paid much attention to volcanic ash layers intercalated in these sediments and they introduced tephrostratigraphy into the studies. In this way, the sediments in each sedimentary basin of those districts were compiled; the Osaka Group by Itihara(1960), the Kobiwako Group by Takaya(1963) and the Agé Group (the Tokai Group on the west coast of Ise Bay) by Takehara(1961). Based on those works, Ishida and Yokoyama(1969) proposed correlation scheme for those sediments throughout the areas.

Plant remains which were yielded from them were classified in detail by Miki(1948), and they were studied stratigraphically by Huzita(1954). Further, Itihara(1960) proposed "*Metasequoia* flora flourish age" and "*Metasequoia* flora extinction age" for Plio-Pleistocene turnover on the basis of his biostratigraphical study. Furthermore, Ikebe et al.(1966) and Kamei and Setoguchi(1970) summarized stratigraphical distribution of the fossil mammalian fauna.

As for paleogeography and tectonism, some significant concepts have been introduced such as "Foundation folding"(Makiyama, 1956), "Rokko Movements"(Ikebe, 1956 and Ikebe and Huzita, 1966) and "First and Second Setouchi Inland Sea"(Ikebe, 1956).

As for the Plio-Pleistocene sediments on the west coast of Ise Bay, Ogawa(1919) studied first and called them the Agé lignite bearing formation. Thereafter, Takimoto(1935) renamed them the Agé Series. Besides, many stratigraphic studies were carried out in various areas (Suzuki et al., 1947, 1948; Akamine et al., 1951; Araki, 1953; Matsui, 1943; Kato, 1957). Fossil elephants such as Stegodon cf. elephantoides and Stegodon akashiensis were reported by Makiyama(1938), Matsui(1943) and Kakuta and Akamine(1958), and also Miki(1948) and Yasuda(1957) studied plant remains.

In the stratigraphic investigation for the Tokai Group on the west coast of Ise Bay (Agé Group), Takehara(1961) descriminated as T_1- T_{20} volcanic ash layers intercalated in that group. By his result, the stratigraphy and geological structure of the group became to be clear, but there were some problems on the identification of the volcanic ash layers and also on the relation between lithology and tephrostratigraphy. Stratigraphic studies on the Agé Group have been continued after then (Takehara, 1966; Hata, 1967; Yokoyama, 1971). Moreover, Ishida and Yokoyama(1969) called the Plio-Pleistocene sediments around Ise Bay collectively

Tokai Group, because those sediments were considered to have been deposited in a single sedimentary basin (Lake Tokai).

Recently, the integration of paleomagnetic and radiometric studies has provided accurate geochronological framework for the Late Neogene, especially for the last 5 m.y. B.P. These studies are also helpful to establish stratigraphy of the Plio-Pleistocene sequences in Kinki and Tokai districts.
The informations from the Kobiwako and Osaka Groups have been accumulated, but those from the Tokai Group have been left behind from such contemporaneous studies.

B. GEOLOGICAL OUTLINE

Generally, in Southwest Japan have been recognized three Neogene geologic provinces, "Hokuriku-San'in" (Japan Sea side), "Setouchi" (Median Zone), and "Nankai" (Pacific Ocean side). The area around Ise Bay can be treated as a depression situated in the eastern part of the "Setouchi" geologic province, bordered by the Suzuka Mountains meridionally on the western margin of that depression. To the east of the depression, the Mikawa Highland lies, and the Mino Massif is located to the north. The Yoro Mountains runs through from northwest to southeast in the northern part of this area and divides the depression into two parts, western half "Age Subbasin", and the other half "Nagoya Subbasin" to be called herein. To the west of the "Agė Subbasin", the Suzuka Mountains runs from south to north with the altitude from 800 to 1,200 m (Fig. 2). To the northeast, the Yoro Mountains ranges from northwest to southeast with the altitude from 600 to 850 m. In foothill areas of those two Mountains, the hills composed of the Miocene and Plio-Pleistocene sediments spread widely with 40 to 300 m height. In the foot of the Yoro Mountains, terraces are remarkably developed along the Inabe River and are developed in the direction at the right angle to the Mountains. Those terraces have the highest level of 250 m. Along the Suzuka Mountains, terraces are also developed along main water courses of the present rivers. The Suizawa Fan which develops at the north of Kameyama City is remarkable in its wide-distribution, with the height from 180 to 40 m. Alluvial plains are distributed along the coast of Ise Bay and rivers.

Geology on the west coast of Ise Bay is divided into the followings: the Mesozoic and Paleozoic formations, the Ryoke metamorphic rocks and granites, the Cretaceous granites, the Miocene deposits of the Ichishi, Suzuka Groups and Chigusa Formation, the Plio-Pleistocene Tokai Group, the Pleistocene Rengeji Formation and its equivalents, terrace and alluvial deposits (Table 1 and Fig. 2).

The Mesozoic and Paleozoic formations are mainly composed of sandstone, shale, chert, limestone and green rocks, and

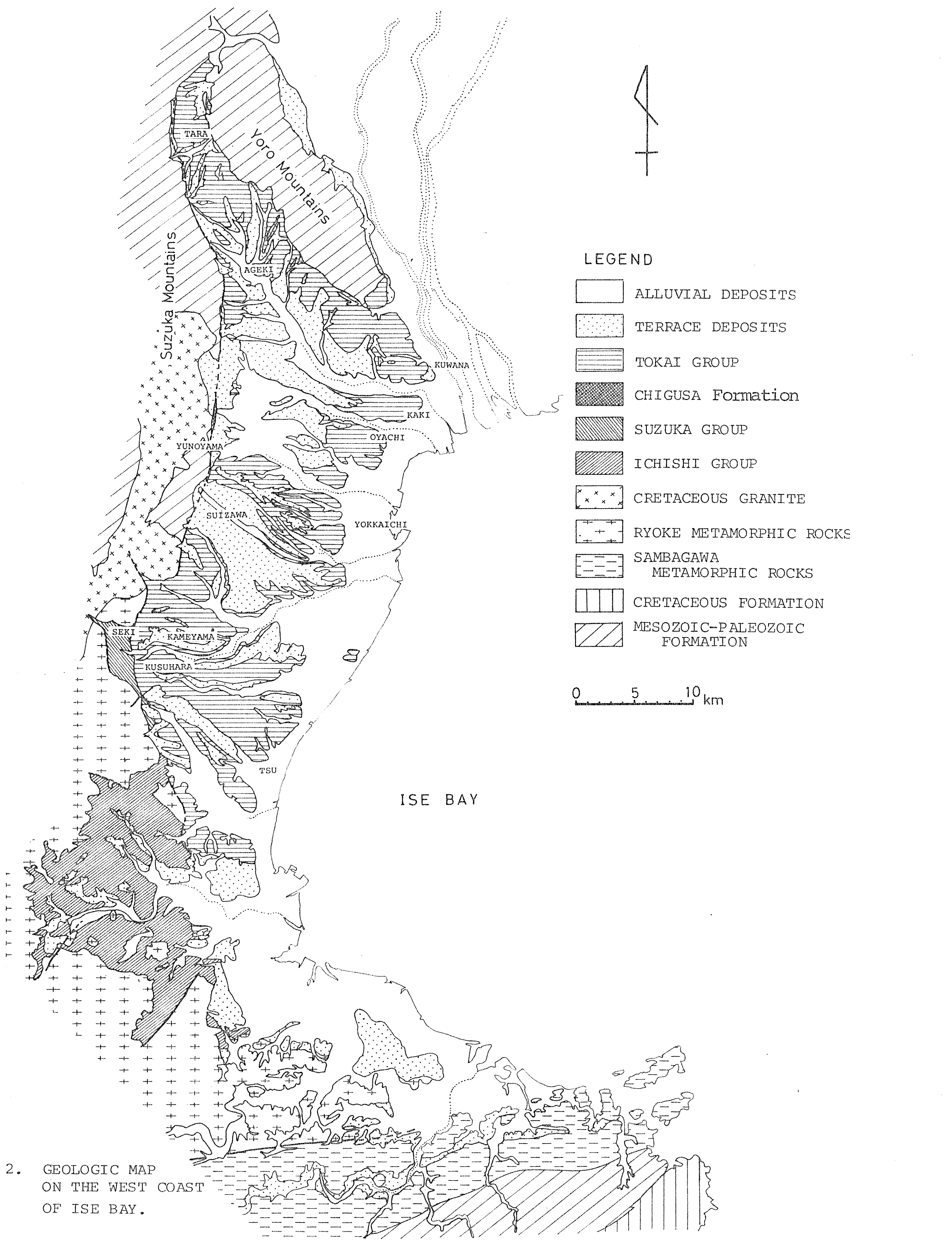


Fig. 2. GEOLOGIC MAP ON THE WEST COAST OF ISE BAY.

Table 1. Geologic system in the west coast of Ise Bay.

Holocene	Alluvium
Pleistocene	Terrace deposits
	Rengeji / Kentoyama Formation
Pliocene - Pleistocene	Tokai Group
Miocene	Ichishi / Suzuka Group Chigusa Formation
Pre-Neogene	Granite Ryoke Metamorphic Rocks Mesozoic-Paleozoic Rocks

they are exposed at the Yoro Mountains and the northern half of the Suzuka Mountains which are the northern part of the depression. The Ryoke metamorphic rocks and granites are distributed in the southern part of the Suzuka Mountains which lies at the main and the southern parts of the depression. The Cretaceous granites are also exposed in the central part of the Suzuka Mountains.

The Miocene Ichishi Group composed of marine sediments belonging to the First Setouchi Supergroup is distributed in hilly zones in the southern part of the depression. Also, the Suzuka Group is distributed in the Seki district (west of Kameyama) which is at the central part of the depression. Its upper part consists of marine sediments, while middle and lower parts are composed of lacustrine sediments. The Miocene Chigusa Formation is also marine deposits which are found in a narrow area between the Cretaceous granites and the Plio-Pleistocene sediments been distributed along the Ichishi Fault in the eastern foothill of the Suzuka Mountains.

The Plio-Pleistocene Tokai Group is distributed in the hilly districts (40-300 m in height) extending from northern Sekigahara to southern Matsusaka City with a length of about 100 km in N-S direction. These sediments consist mainly of gravels, sands, muds in fluvial and lacustrine origin and intercalated with numerous volcanic ash layers and lignite beds.

Generally speaking, in the southern part (Nanse area around Tsu and Kameyama Cities), the lower part of this sequence is distributed, and in the northern part (Hokuse area) the upper part of it.

Middle Pleistocene sediments such as the Rengeji and Kentoyama Formations overlie unconformably the Tokai Group. The Rengeji Formation is distributed at the marginal parts of the hills along the Yoro Mountains, and at the top of the hills to the west of Karegawa and to the north of Rengeji. It is chiefly composed of gravels, containing mostly cobble to pebble size gravels, and contains the seams of silt and lignite. Ninety five per cent of gravels is chert and sandstone. On the other hand, the Kentoyama Formation consists of gravels, sands and muds, and is distributed around Tsu City. These formations can be correlated with the Taketoyo Formation of the Chita Peninsula, which is intercalated with some marine muddy layers (Makinouchi, 1975b). Terrace deposits are composed mainly gravels, but marine fine-grained facies is intercalated in the Middle terrace deposits.

C. LITHOSTRATIGRAPHY OF THE TOKAI GROUP

The main surveyed areas in this study are shown in Figs. 3 and 4, and they occupy the central and northern part of the distribution of the Tokai Group on the west coast of Ise Bay. As it is one of the characteristics of the Tokai Group that lateral variation of lithofacies is conspicuous, it is convenient

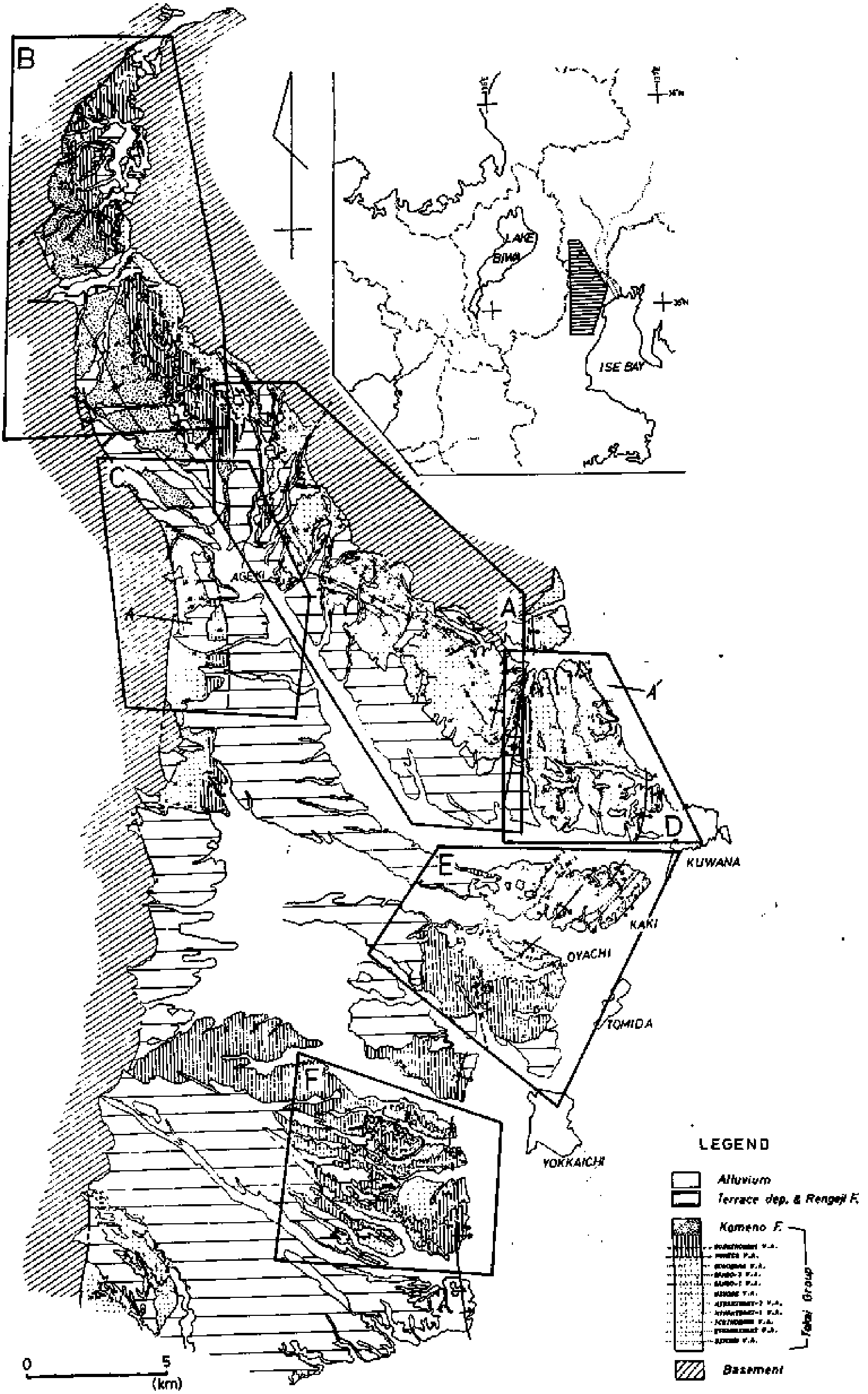


Fig. 3. Geologic map in the northern part of the west coast of Ise Bay (Hokuse area) and index map of the surveyed area.

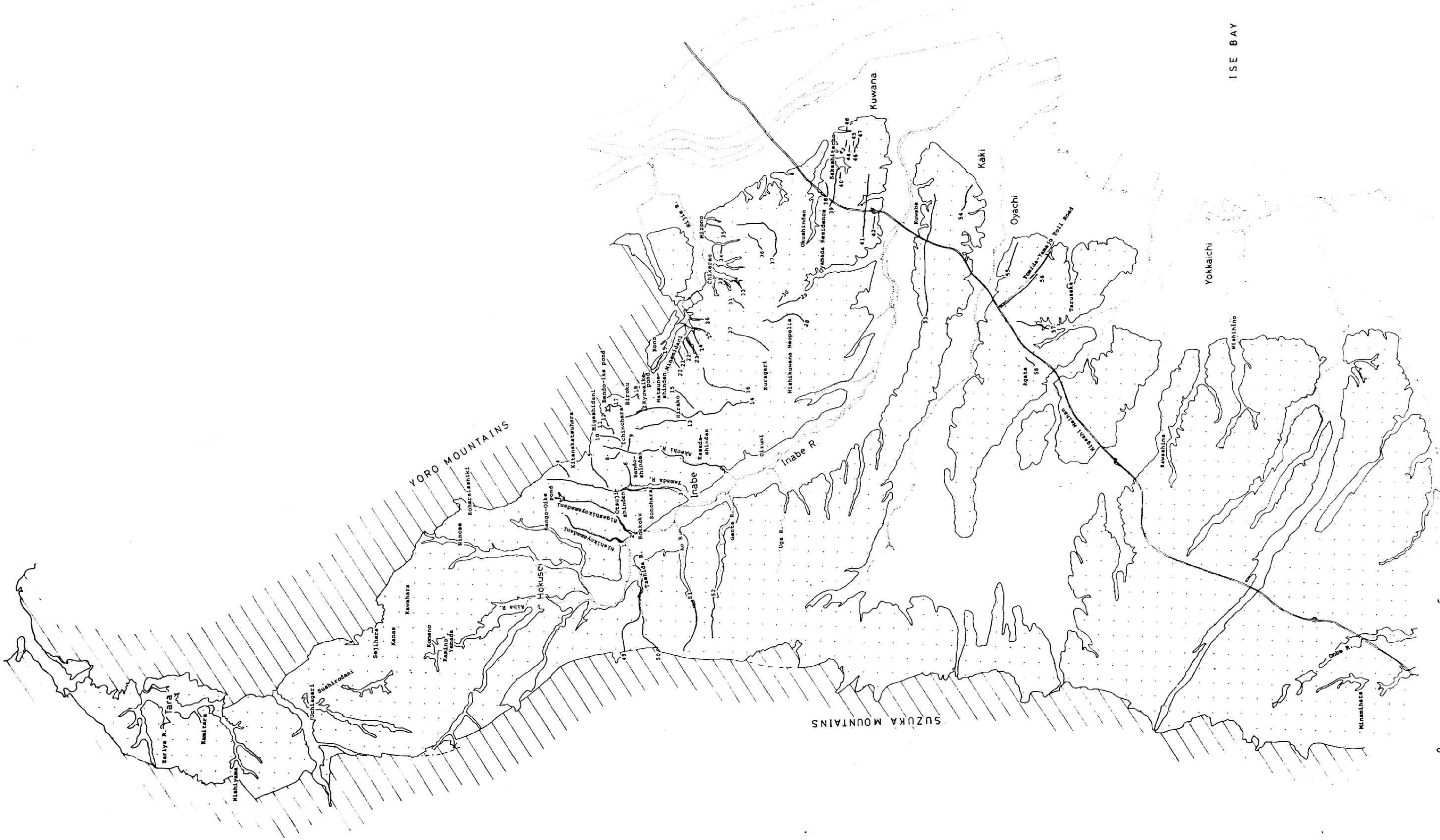


Fig. 4. Locality map in Hokuse area.

at first to describe the lithology of the Tokai Group in the Hokusei and Inabe district as the type area (Fig. 3-A), where the most continuous sequence and stable lithofacies can be observed. Thereafter, lithology of the Tokai Group in other five areas (Fig. 3 B-F) will be described and compared with that of the type area. Stratigraphy in each area is summarized in Table 2.

a. Hokusei and Inabe area (Fig. 3-A)

The Tokai Group in this area (about 950 meters in thickness) forms hills at the southwestern foot of the Yoro Mountains, and dips to southwest. It is divided into six formations such as Biroku (gravels), Kono (alternating beds of sand and mud), Ichinohara (alternating beds of gravel and mud), Kuragari (gravels with mud and sand layers), Oizumi (alternating beds of sand and mud) and Komeno (gravels) Formations in ascending order (Table 3). These sediments intercalates at least twenty five volcanic ash layers. The geologic map and columnar sections are shown in Figs. 5, 6 and 7.

1. Biroku Formation (Matsui, 1943)

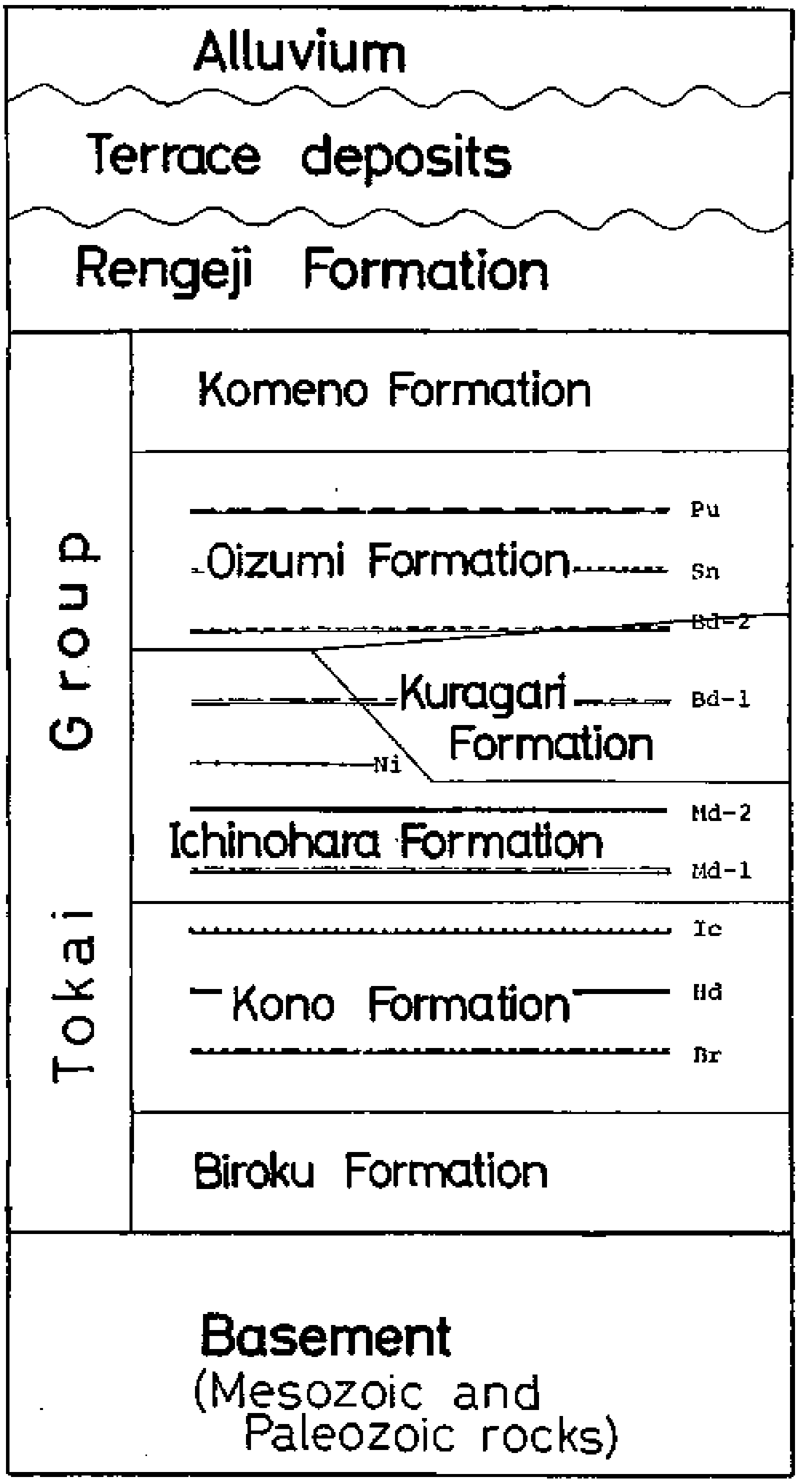
Type locality: the area around the Bandoike pond to the northwest of Biroku village

This formation is composed mainly of gravels of bluish green sandstone which were derived from the basement of the Mesozoic and Paleozoic formations. Gravels are subround and subangular in shape, and are cobble, pebble to small boulder

Table 2. Stratigraphy of the Tokai Group in Hokuse area.

FORMATION \ AREA	TARA	SUZUKA	HOKUSEI	KUWANA	KAKI & OYACHI	YOKKAICHI
KOMENO FORMATION	gravel	gravel	gravel			
OIZUMI FORMATION	alternation of mud & gravel "TARA FACIES"	alternation of mud & sand partly gravel	alternation of mud & sand "INABE FACIES"	alternation of mud & sand	sandy alternation of mud & sand partly gravel	sand & gravel sandy alternation of mud & sand partly gravel
KURAGARI - ICHINOHARA FORMATION	ICHINOHARA F. alternation of gravel & mud	ICHINOHARA F. alternation of gravel & mud	sand & gravel alternation of gravel & mud	KURAGARI F. sand & gravel alternation of sand & mud "KUWANA FACIES"	KURAGARI F. sand & gravel alternation of sand & mud	
KONO FORMATION		alternation of mud & sand	alternation of mud & sand	alternation of mud & sand		
BIROKU FORMATION		gravel	gravel			

Table 3. Stratigraphy of the Tokai Group in Inabe and Hokusei area.



Volcanic Ashes

Pu ; Pumice	Ni ; Ninose	Hd ; Higashidani
Sn ; Sonohara	Md-2 ; Minamidani-2	Br ; Biroku
Bd-2 ; Bando-2	Md-1 ; Minamidani-1	
Bd-1 ; Bando-1	Ic ; Ichinohara	

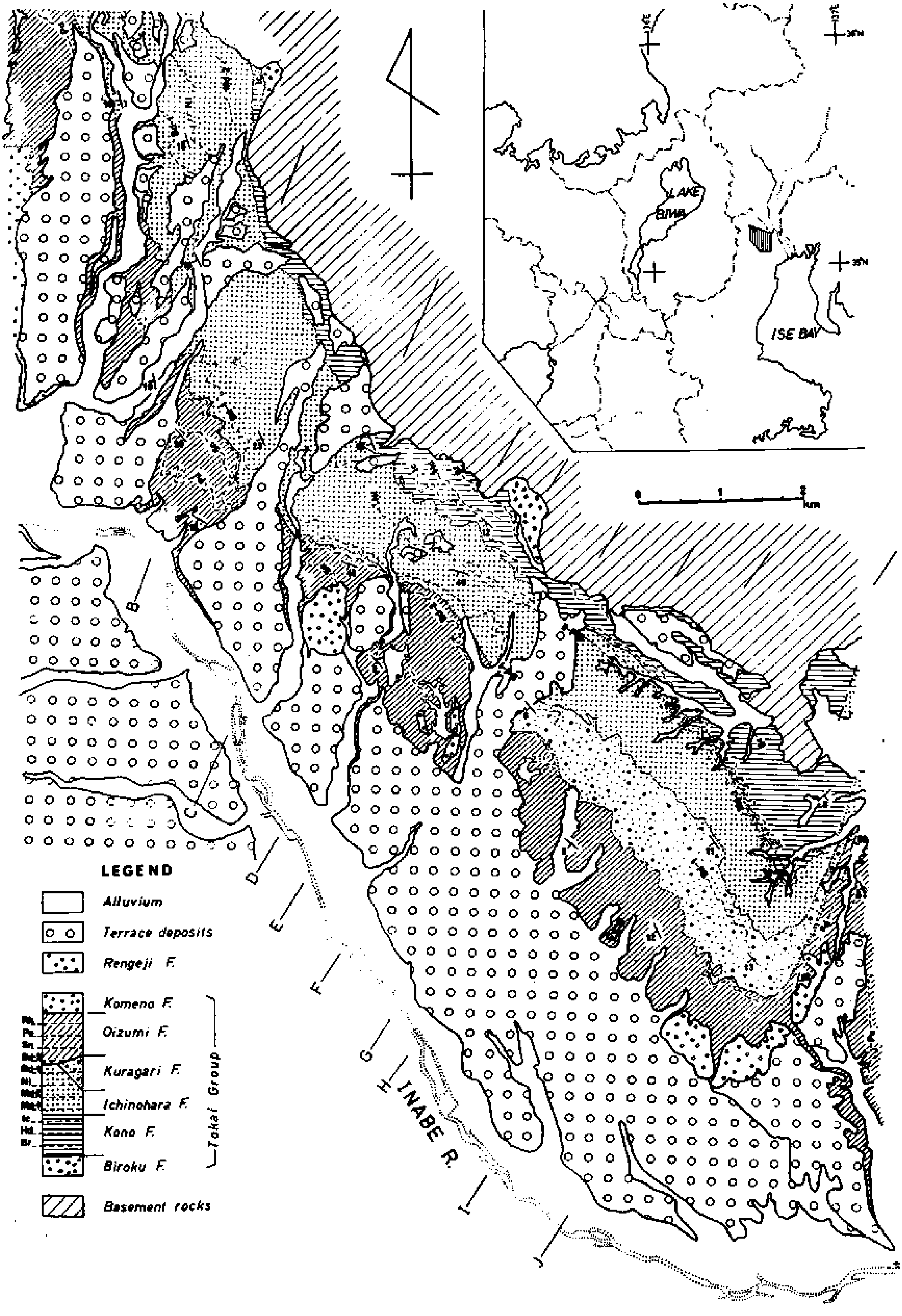


Fig. 5. Geologic map in the Inabe and Hokusei area.

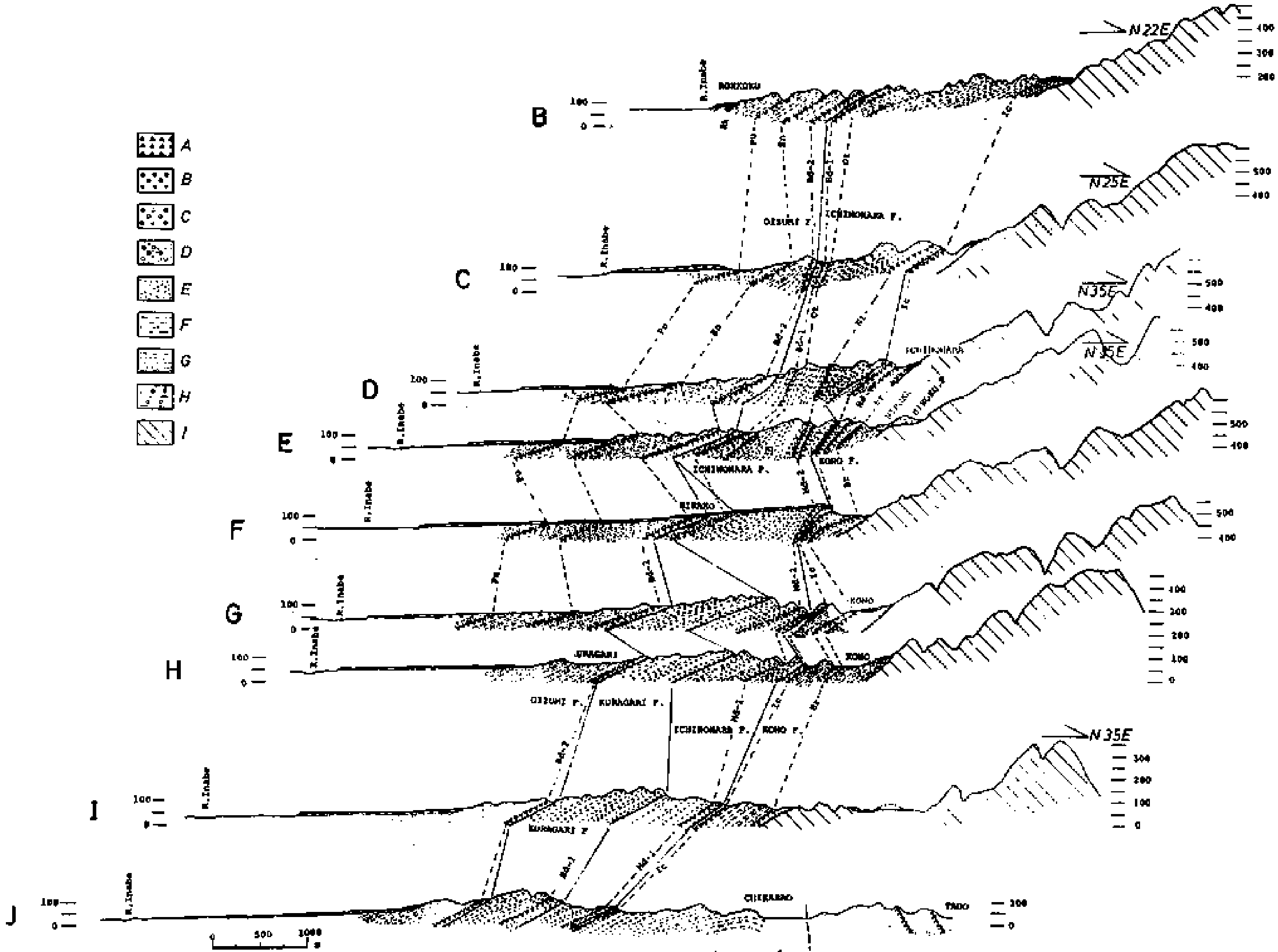


Fig. 6. Geologic profiles in the Inabe and Hokusei area.

Profiling line: see Fig. 5.
A: Terrace deposits B: Rengeji Formation C: gravel D: sand and gravel E: sand F: mud G: alternating beds of sand and mud H: alternating beds of mud and gravel I: basement rocks.

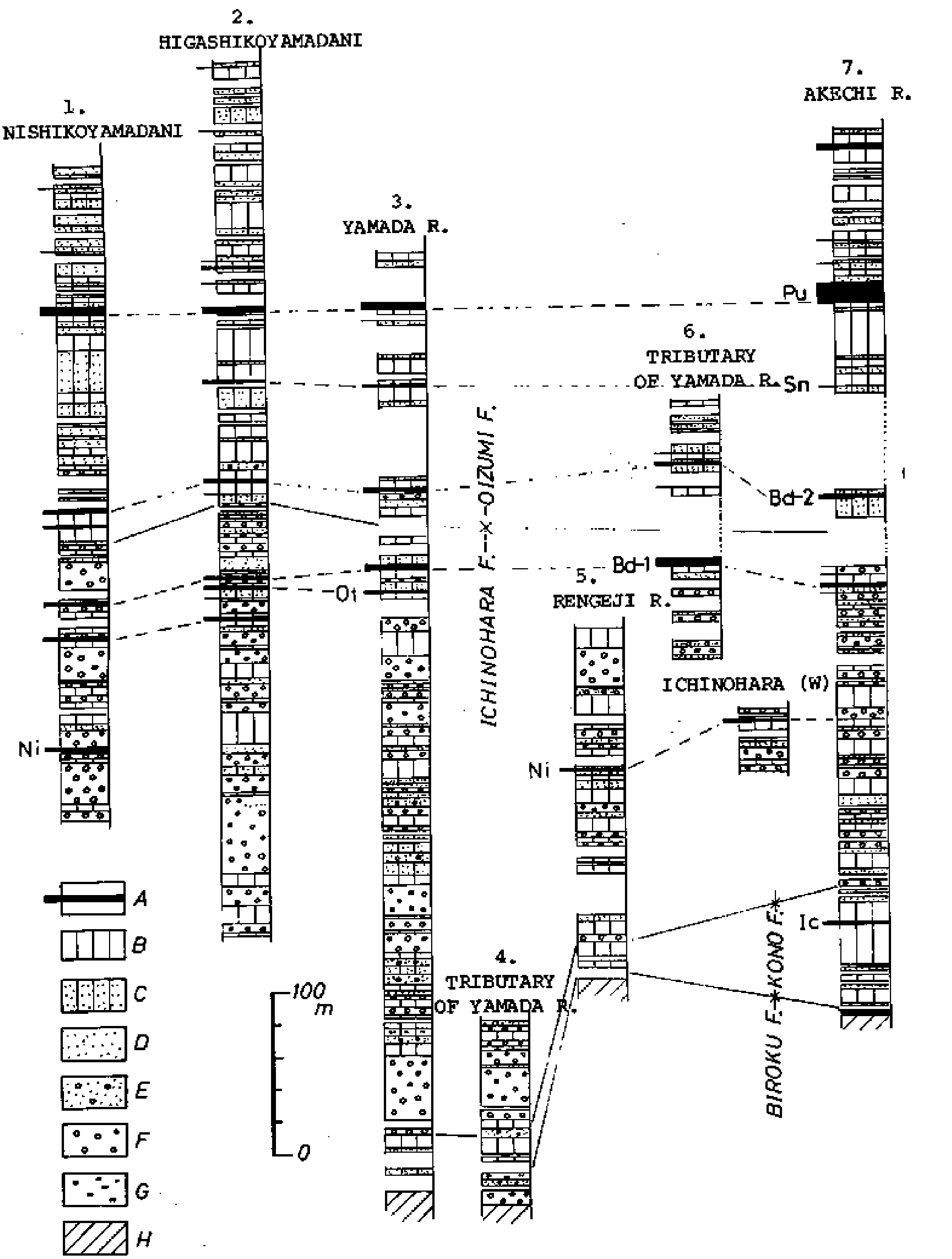


Fig. 7-a. Columnar sections in the Inabe and Hokuei area. (legend: see Fig. 7-b, route No.: see Fig. 4)

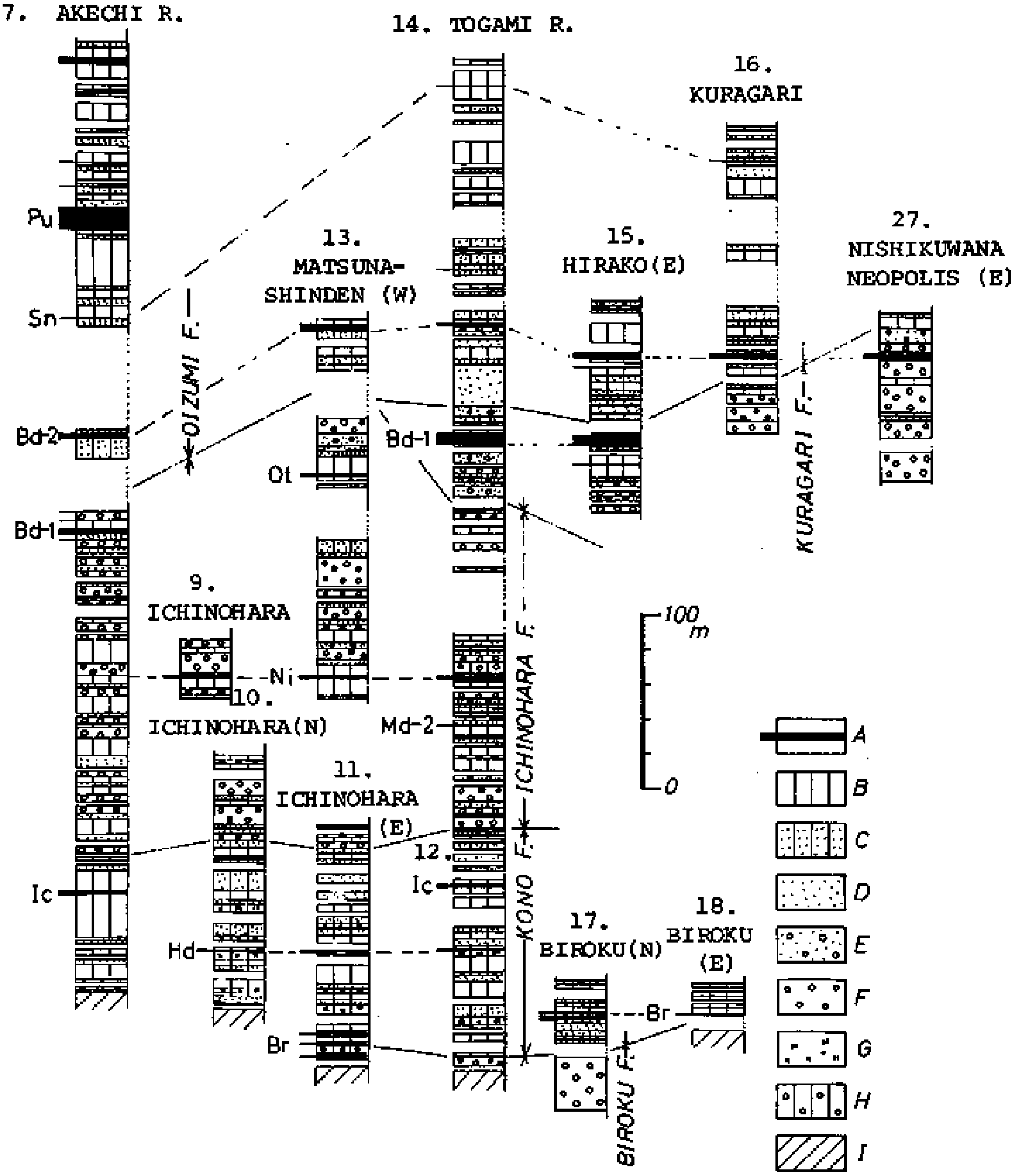


Fig. 7-b. Columnar sections in the Inabe area.
A: volcanic ash layer B: mud
C: alternating beds of sand and mud
D: sand E: sand and gravel
F: gravel G: lignite H: alternating beds of mud and gravel I: basement rocks
(Symbols of volcanic ash layer: see Table 3.
Route No.: see Fig. 4)

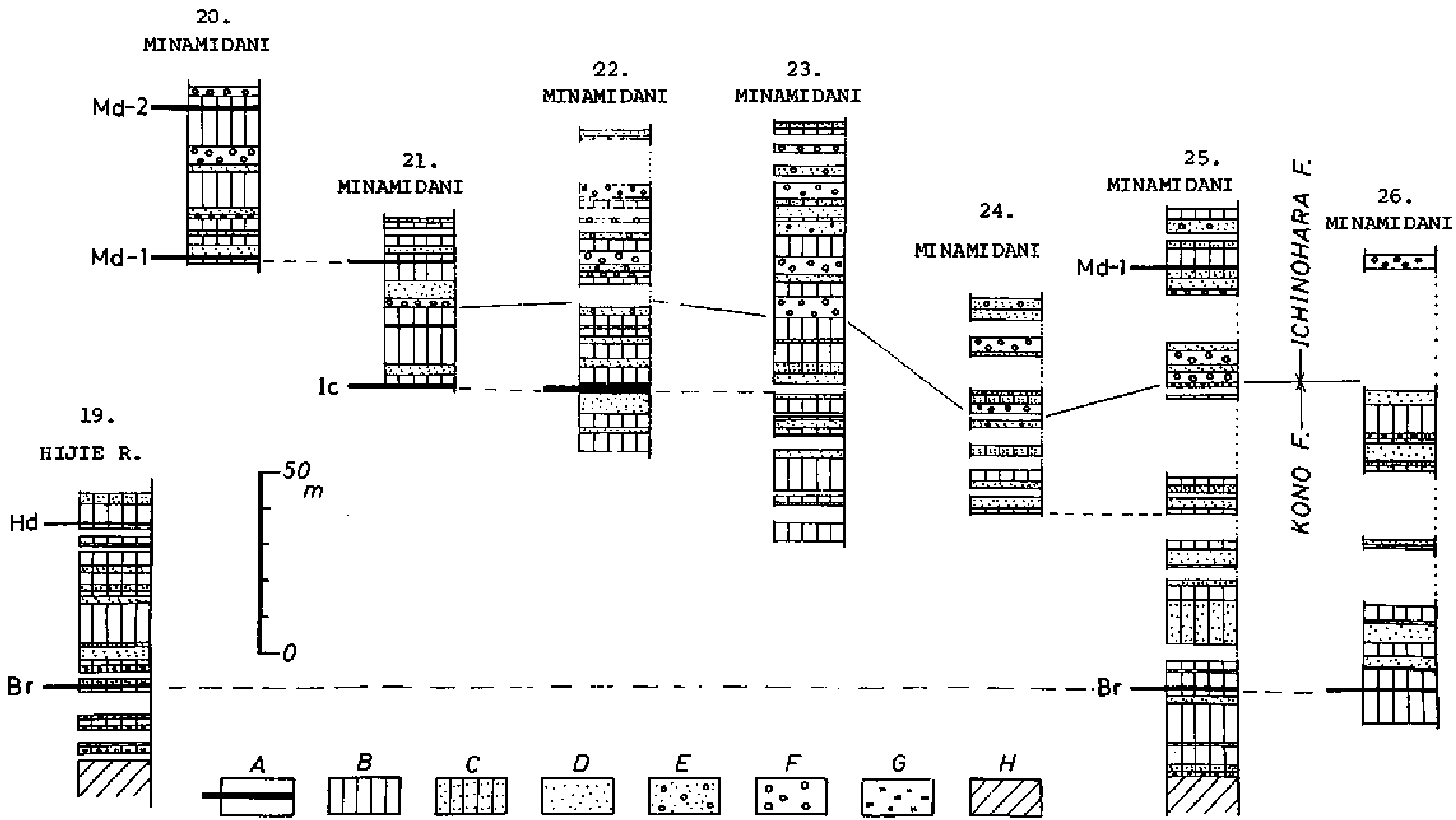


Fig. 7-c. Columnar sections in the Kono area.
(legend: see Fig. 7-b, Route No. see Fig. 4)

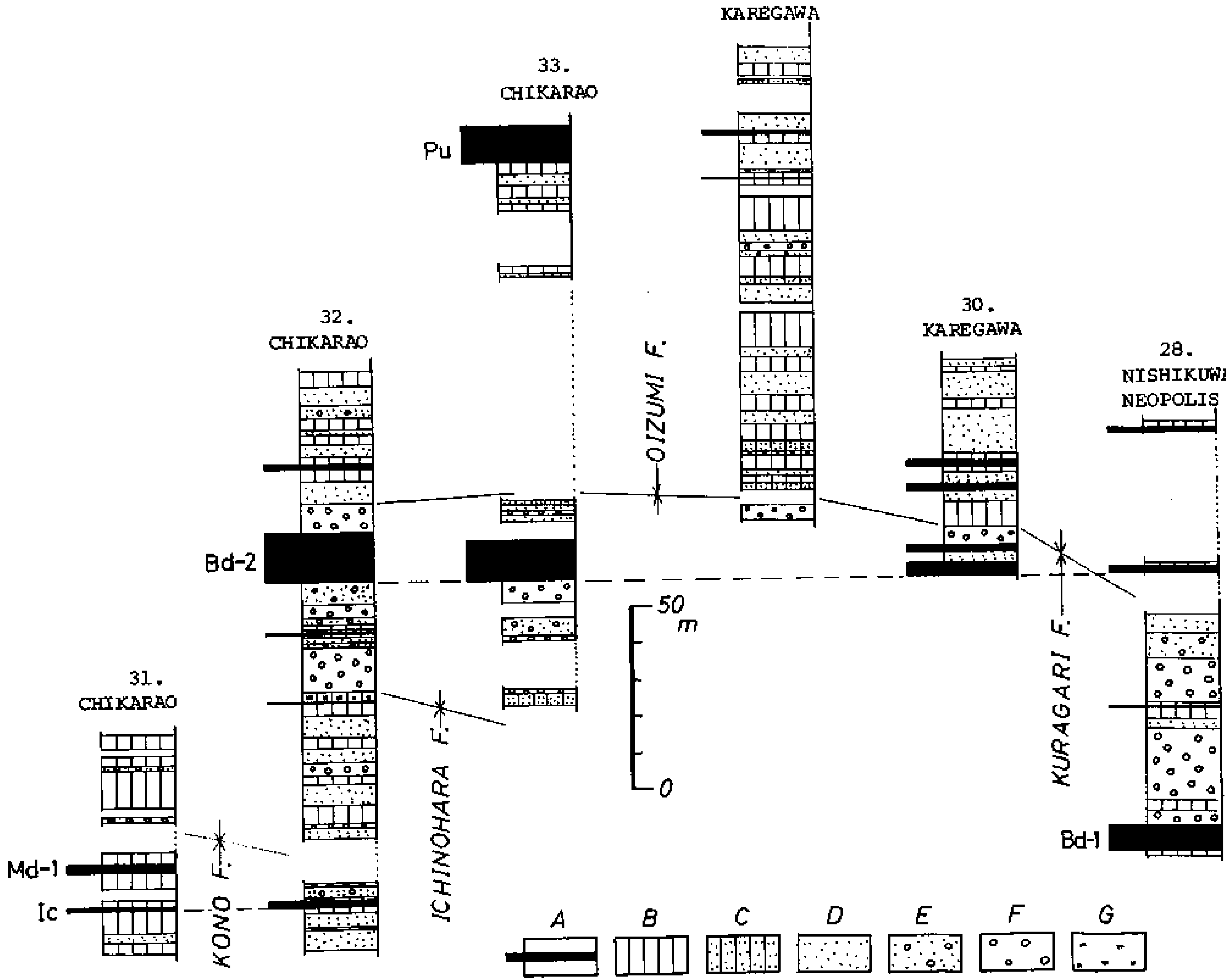


Fig. 7-d. Columnar sections in the Kuragari and Chikarao areas.
(legend: see Fig. 7-b, Route No.: see Fig. 4)

in size. Most gravels are heavily weathered, and the matrix is composed of bluish green colored sands. Distributions are restricted in the foothill zone of the Yoro Mountains.

At the type locality around the Bandoike pond, the gravel bed attains 50 m thick. The lower part is composed mainly of cobble to pebble gravels. A thin lignite seam is intercalated in the uppermost part. The lower part crops out well at the cliff near the pond. At this outcrop, the amount of sandstone gravels reaches to about 95 % and the rests is occupied by chert gravels.

In the north of Kitanakatsuhara, the Biroku Formation unconformably overlies the Mesozoic and Paleozoic sandstone in the upper stream of the Yamada river. Here, this formation is about 15 m thick and is divided into two parts: the lower part of subangular and small boulder gravels and the upper part of subangular pebble and cobble gravels. The underlying sandstone (Mesozoic and Paleozoic formations) is heavily weathered.

2. Kono Formation (Matsui, 1943)

Type locality: Northwest of Biroku

This formation is distributed mainly from Koharaisshiki to Chikarao in the area of southern foothills of the Yoro Mountains. It is composed of alternating beds of massive bluish green mud and sand with lignites and volcanic ash layers. At least five volcanic ash layers are intercalated in this formation, and three of them, the Biroku, Higashidani and Ichinohara volcanic ash layers in ascending order are effective marker beds.

The thickness of this formation decreases westward: about 110 m in Kono, but about 25 m in Kitanakatsuhara. Generally, the Kono Formation abuts on the Mesozoic and Paleozoic rocks and overlies conformably the Biroku Formation.

At the cliff along the way from Ichinohara to Biroku, the Kono Formation is typically exposed. The sediments of about 16 m thick are observed, which are composed of muddy alternation of mud and sand beds with seven lignite seams. Three volcanic ash layers are intercalated, and the uppermost one is the Biroku volcanic ash layer.

The columnar sections around Kono are shown in Fig. 7-c. This formation of about 110 m thick is divided into two parts. The lower part is composed of mud layers with many lignite beds, and the upper part is muddy alternation of sand and mud beds. The lower part is well exposed at the riverbed and riverside of the Hijie river. On the riverbed at the east of Kono, the Mesozoic and Paleozoic shale heavily weathered crops out, where the mud of the Kono Formation overlies unconformably the basement rocks (Fig. 8). The upper part of the Kono Formation is exposed at a cliff of Minamidani, and the sediments of about 39 m thick can be observed. In the middle of the cliff, a volcanic ash layer, of black gray color in the lower and yellowish green color in the upper, occurs. This is the Ichinohara volcanic ash layer.

At the north of Ichinohara, the Kono Formation is well

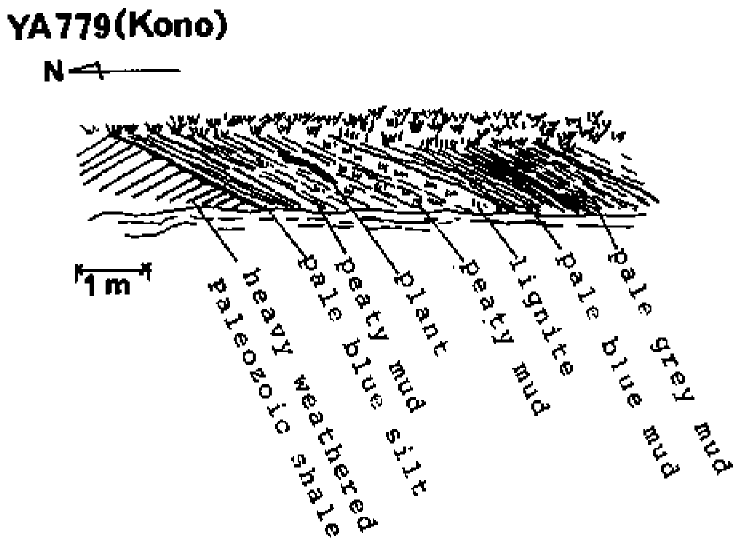


Fig. 8. Sketch of the unconformity between the Mesozoic-Paleozoic formation and the Kono Formation at the riverside of the Hijie river in Kono.

exposed in the upper stream of the Akechi river and at Higashidani. In the former place, it is about 75 m thick, and in the latter, about 120 m thick.

3. Ichinohara Formation (Matsui, 1943)

Type locality: At the valley to the west of Matsunashinden

This formation is composed mainly of alternating beds of mud and gravel, and overlies conformably the Kono Formation. In the area to the north of Kawahara, however, it abuts directly on the Mesozoic and Paleozoic rocks. The thickness of this formation attains to 220 m near Ichinohara, and to 350 m along the Yamada river. In the area to the west of Hirako, the upper part of the Ichinohara Formation grades into the overlying Kuragari Formation. At least nine volcanic ash layers are intercalated in this formation, and five of them are effective marker beds. They are called the Minamidani-1, Minamidani-2, Ninose, Otsujishinden, and Bando-1 volcanic ash layers in ascending order.

There is a representative outcrop at the west side of Kyowaike pond in the valley to the west of Matsunashinden. At this place, the beds strike northwest by west and dip 50° south. Thickness of the sediments is about 47 m. Six gravel beds can be observed, and the thickness of each ranges from 1 m to 9 m. Gravels are subround in shape and cobble to pebble in size. The amount of gravels, sands and muds in the sediments at this outcrop is 31.5 %, 24.0 % and 44.5 %, respectively.

Two thin lignite seams are observed. A light gray hard volcanic ash layer (the Ninose volcanic ash layer) is intercalated in a lignite bed at a middle horizon.

In Higashikoyamadani valley, the Ichinohara Formation is well exposed at 2 km downstream from the south end of the Sango-oike pond. The sediments are about 260 m thick. They are composed mainly of the alternating beds of gravel and mud. In this valley, the cliff about 200 m downstream from the Sango-oike pond can be nominated as a representative outcrop. The sediments are 46 m thick, composing of cobble to pebble gravels (12 m in thickness), bluish gray mud (9 m), gravels (11 m), lignite (0.2 m), bluish gray mud (11 m) and gravels (3 m +) in descending order. At another cliff about 1.2 km downstream from the Sango-oike pond, the sediments of 34 m thick are observed. Three volcanic ash layers can be detected in the gravel facies. Among them, the uppermost one is assigned to the Bando-1, and the middle one is to the Otsujishinden volcanic ash layer.

In the neighborhood of Ichinohara, the typical outcrop is located at the south of Ichinohara (Fig. 9). Thickness of the sediments is about 34 m. The upper part is composed of gravels and muds. The thickest gravel bed is 9 m thick. The lower part is composed of muds with sands, and the Ninose volcanic ash layer is intercalated with peaty mud.

4. Kuragari Formation (Matsui, 1943)

Type locality: hills to the north of Kuragari village

This formation is composed mainly of gravels with a small

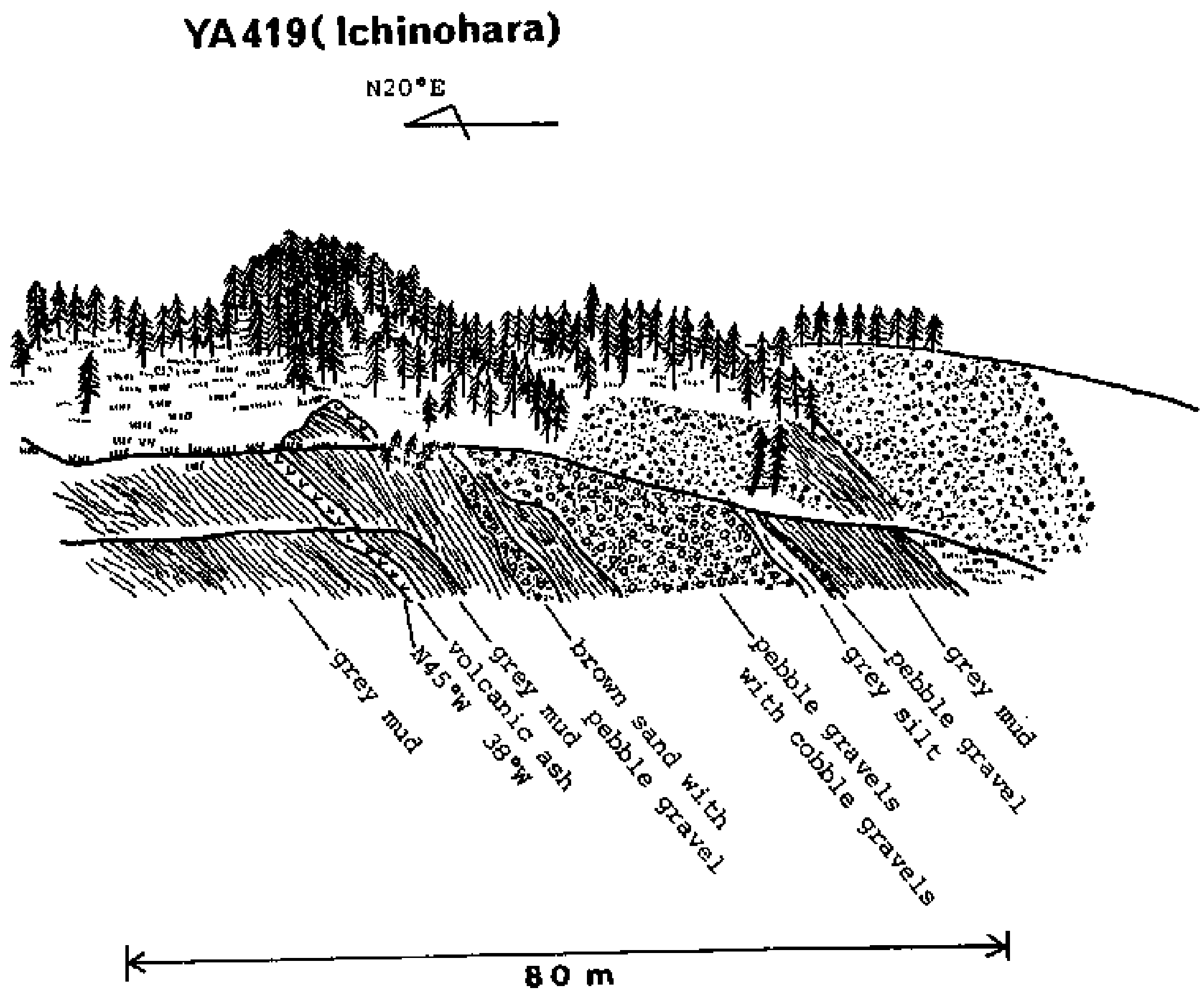


Fig. 9. Sketch of the typical outcrop of the Ichinohara Formation in the

amount of mud and sand layers. At least five volcanic ash layers are intercalated within this formation, and among them, the Bando-1 volcanic ash layer is useful as a key bed. Gravels are pebble to cobble in size, and are dominated by chert, sandstone and quartz porphyry, with matrix of coarse to medium sand. In total, the amount of chert is about 50-70 % and that of quartz porphyry is about 20-30 %. The Bando-1 volcanic ash layer is also commonly found in the upper part of the Ichinohara Formation in northern part of Hokusei area. This formation is distributed only in the area to the east of Hirako. The thickness of the deposits increases eastward and northward.

In the type area, a topographic asymmetry can be seen between Kuragari and Kono, which has the ridge being steeper to the north. Along this ridge, the Kuragari Formation are well exposed. The lower part is composed mainly of gravels, while the upper part is composed of sands and gravels. In Nishikuwana Neopolis residence area, to the east of the type area, the sediments attain about 90 m in thickness. They are compose mainly of cobble to pebble gravels with mud and sand layers and an amount of sand increases to the upper. The maximum thickness of gravel bed is about 35 m.

5. Oizumi Formation (Matsui, 1943)

Type locality: at the valley in the western area of Kasadashinden (the Akechi river)

This formation is composed mainly of alternating beds of sand and mud with some lignites and volcanic ash layers, and is about 360 m thick. At least ten volcanic ash layers are intercalated in this formation, and four of them, Bando-2, Sonohara, Pumice and Rokkoku volcanic ash layers in ascending order, are available as good marker beds.

Along the Akechi river, this formation is well exposed and the sediments of about 160 m in thickness are observed. They are composed of alternating beds of bluish gray mud and sand. The bed strikes northwest by north to southeast by south, and dips 7-8 degrees west. A thick volcanic ash layer of 13 m thick (Pumice volcanic ash layer) was recognized. The Sonohara volcanic ash layer which is black gray in color and pumiceous is also observed in the upper stream of that point.

6. Komeno Formation

Type locality: a cliff in the west of Komeno

This formation occupies the uppermost part of the Tokai Group. This is composed mainly of gravels which are made of sandstone, shale, siliceous shale and chert. The lower part is commonly composed of granule, pebble and cobble gravels, while the upper part is represented by cobble with boulder gravels. This formation is distributed mainly in Tara area (Fig. 3-B).

b. Tara area (Fig. 3-B)

The Tokai Group in this area was reported by Yokoyama (1971) and Miyamura et al. (1976) as shown in Figs. 10 and 11. According to them, the deposit in this area is 650 m in thick-

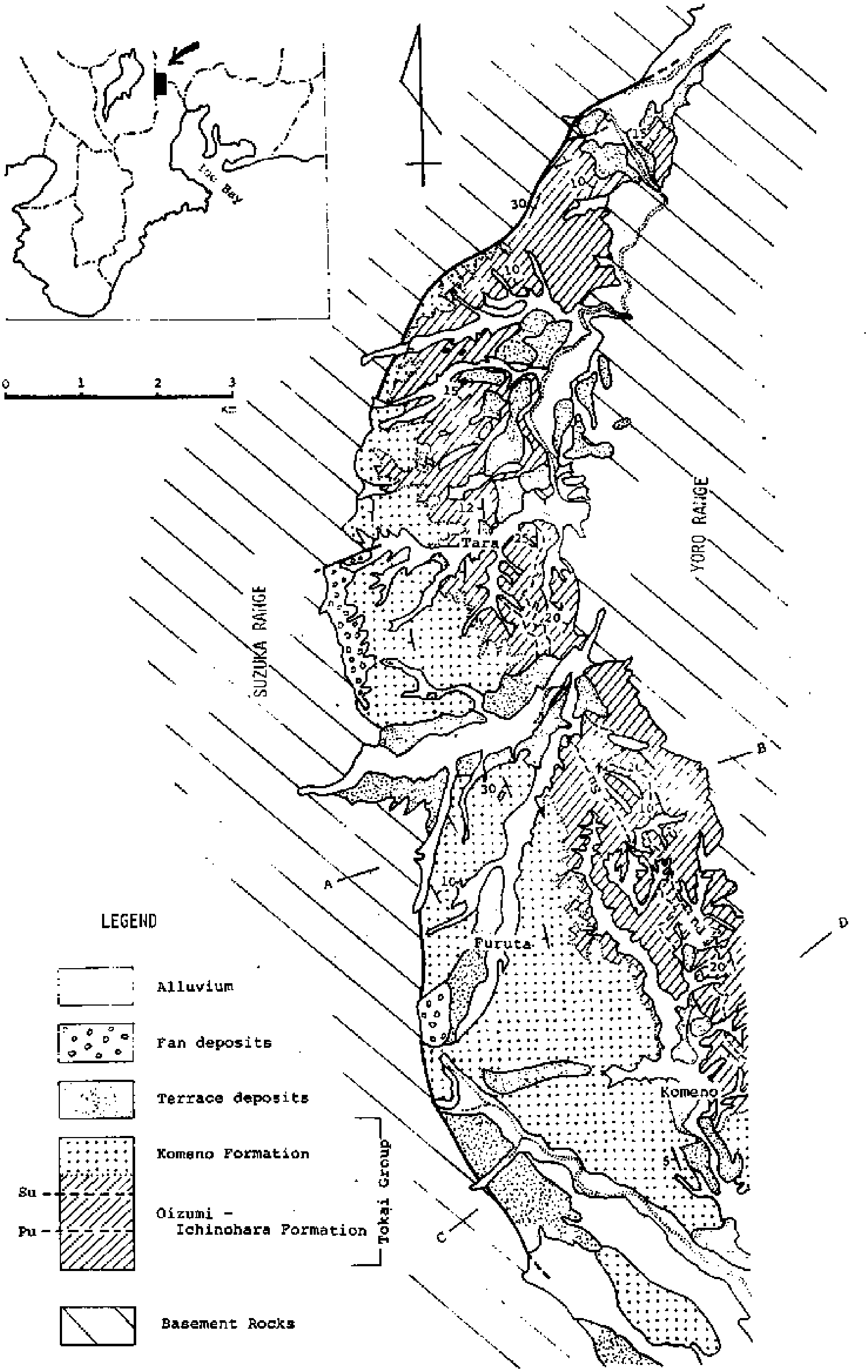


Fig. 10. Geologic map in the Tara area (after Miyamura et al., 1976).

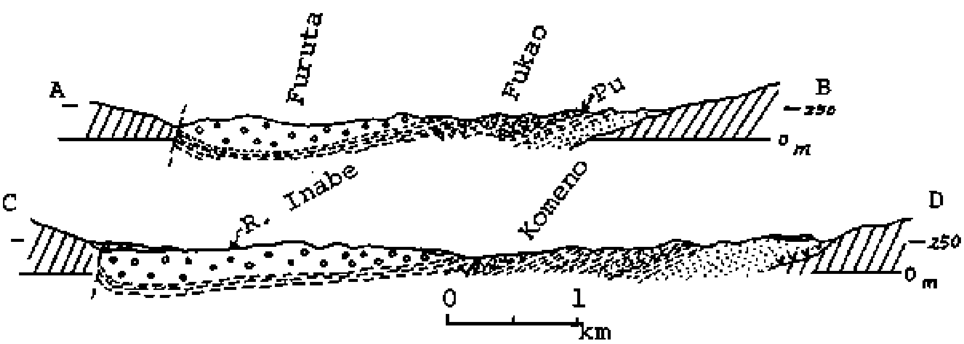


Fig. 11. Geologic profile of the Tokai Group in the Tara area (after Miyamura et al., 1976).

ness and was divided into Ichinohara, Oizumi and Komeno Formations in ascending order. At least fifteen volcanic ash layers are commonly found throughout this area (Fig. 12).

The Ichinohara Formation overlies unconformably the Mesozoic and Paleozoic rocks of the Yoro Mountains. In the neighborhood of Sejihara, there are several good outcrops, and the formation is measured as 50-70 m thick. The sediments are composed mainly of alternating beds of gravel and mud with some sandy layers. The thickness and sedimentary facies are variable laterally. Gravels are cobble to pebble in size, subangular to subround in shape, and are composed mostly of sandstone subordinating with shale, and chert.

The Oizumi Formation reaches to 300 m in thickness, and its sedimentary facies are also variable laterally. At Tara, along the Makita river and Sushirodani valley, the sedimentary facies is very similar to those of the Ichinohara Formation at Inabe area. The author calls this facies "Tara Facies" of the Oizumi Formation. This facies is characterized by alternating beds of gravel and mud. On the other hand, along the Aibagawa river and around Komeno, it is composed of alternating beds of sand and mud with small amount of granule to pebble gravels. The Pumice and Sushirodani volcanic ash layers are intercalated.

The Komeno Formation, the uppermost formation of the Tokai Group, exceeds 300 m thick and thins northward. It is composed mainly of cobble to pebble gravels, with matrix of very coarse

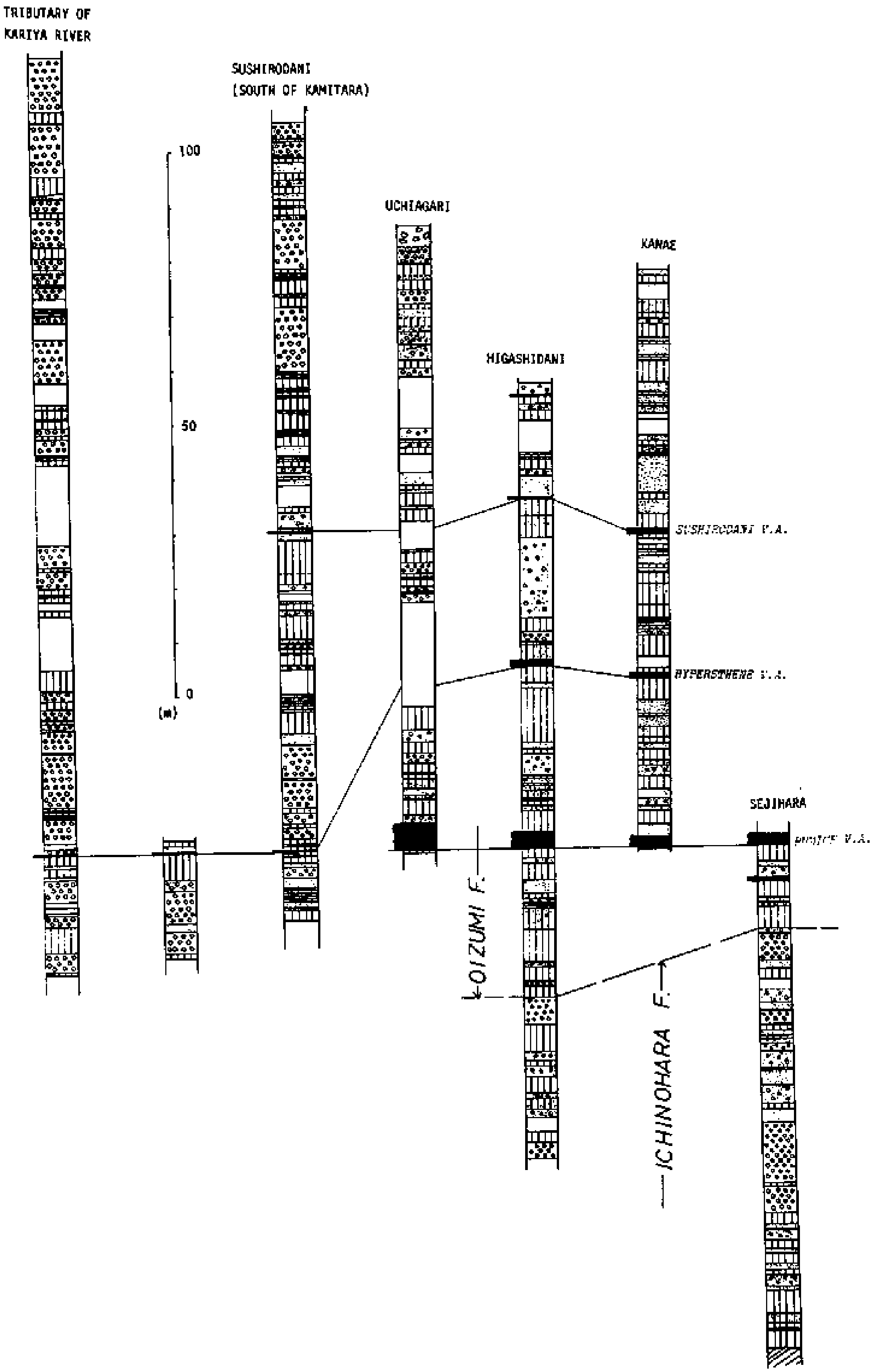


Fig. 12-a. Columnar sections of the Tokai Group in the Tara area (after Miyamura et al., 1976).

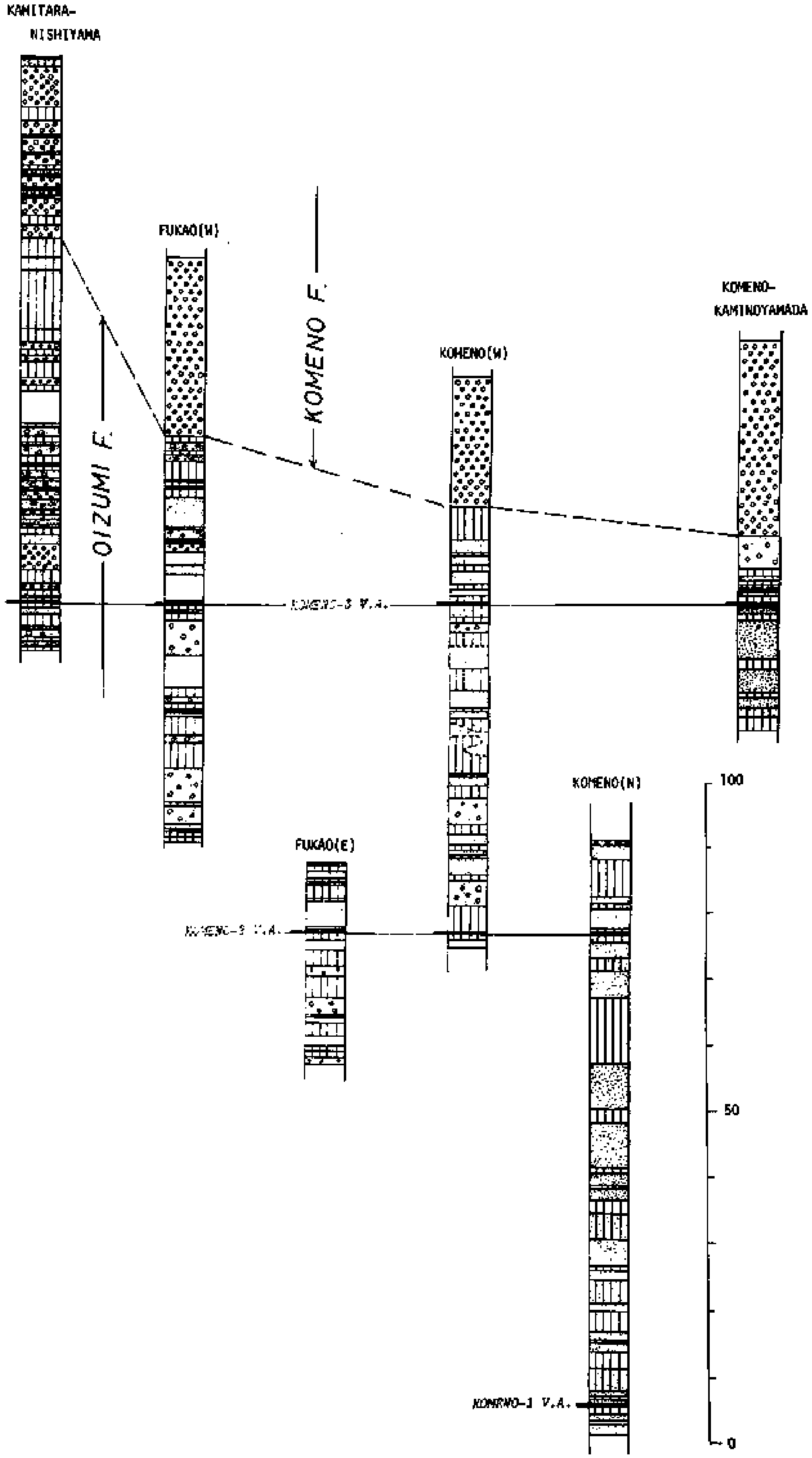


Fig. 12-b. Columnar sections of the Tokai Group in the Tara area (after Miyamura et al., 1976).

sand. Gravels are composed of sandstone (50 %), and subordinating of siliceous shale, shale and chert, and with small amount of quartz porphyry. Type locality of the Komeno Formation is the cliff of the Aibagawa river, to the west of Komeno in this area.

c. Suzuka area (Fig. 3-C)

At the east foot of Suzuka Mountains, the Tokai Group exceeds 800 m in thickness and dips to the east (Figs. 13 and 14). The Tokai Group is divided into the Biroku, Kono, Ichinohara, and Oizumi Formations, and at least seven volcanic ash layers are intercalated (Fig. 15). In the upper course of a tributary of the Tashida river, the Biroku Formation is well exposed. It is 30 m thick and two lignite beds are intercalated in the upper part. It is conformably covered with the Kono Formation. The Kono Formation crops out in the upper course of the Tashida river and its tributaries. It consists of muddy alternating beds of sand and mud with lignite beds. It is about 40 m thick. The thickness of mud layer ranges from 2 to 5 m thick, and that of sand layer is about 2 m thick. A coarse grained crystalline volcanic ash layer named the Ichinohara volcanic ash layer, lies 10 m above the unconformity on the basement rocks.

Also, the Ichinohara Formation is well exposed at the river bed of the Tashida river. In this district, this formation is about 470 m thick, and is divided into two parts. The

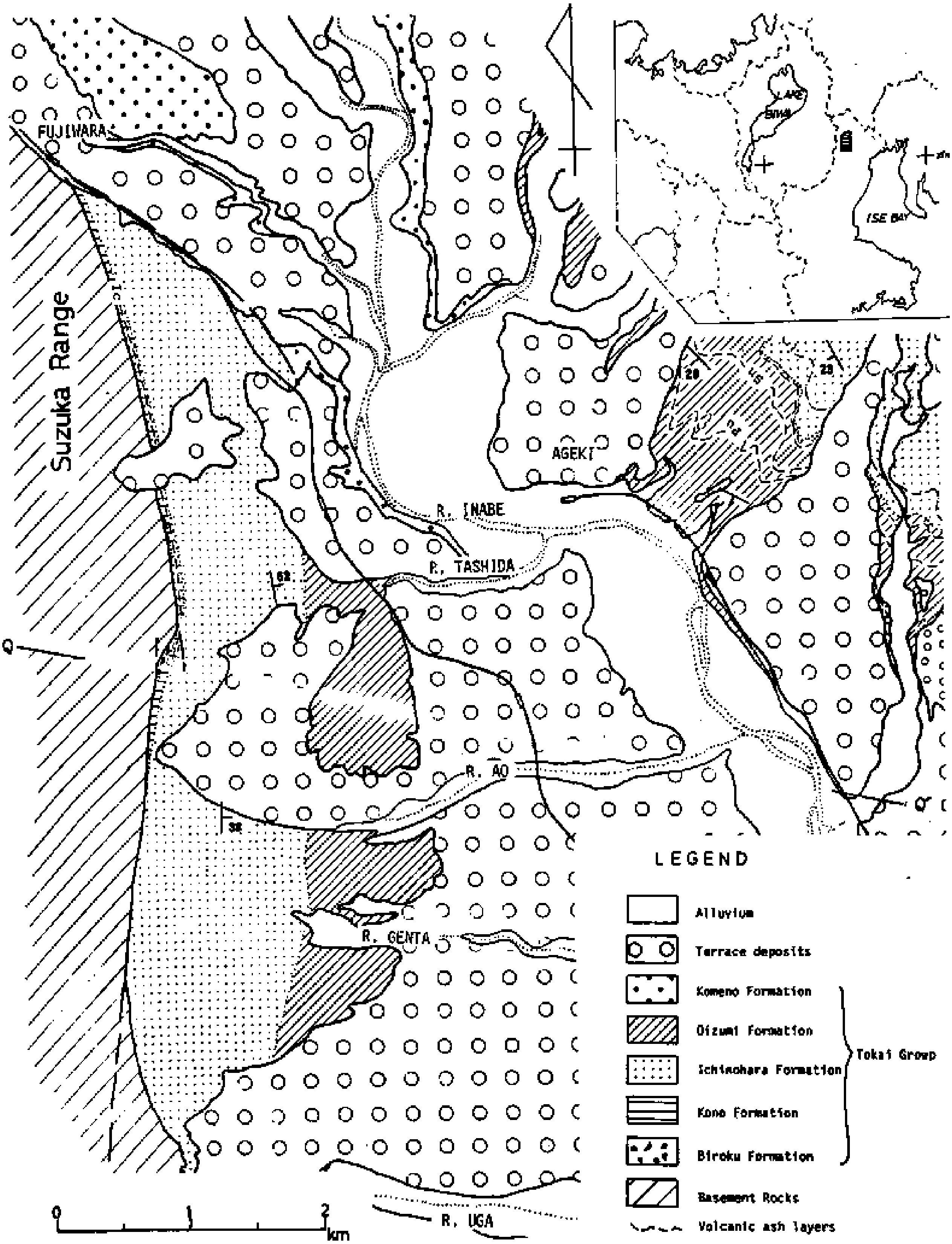


Fig. 13. Geologic map of the Tokai Group in the foot of the Suzuka Mountains.

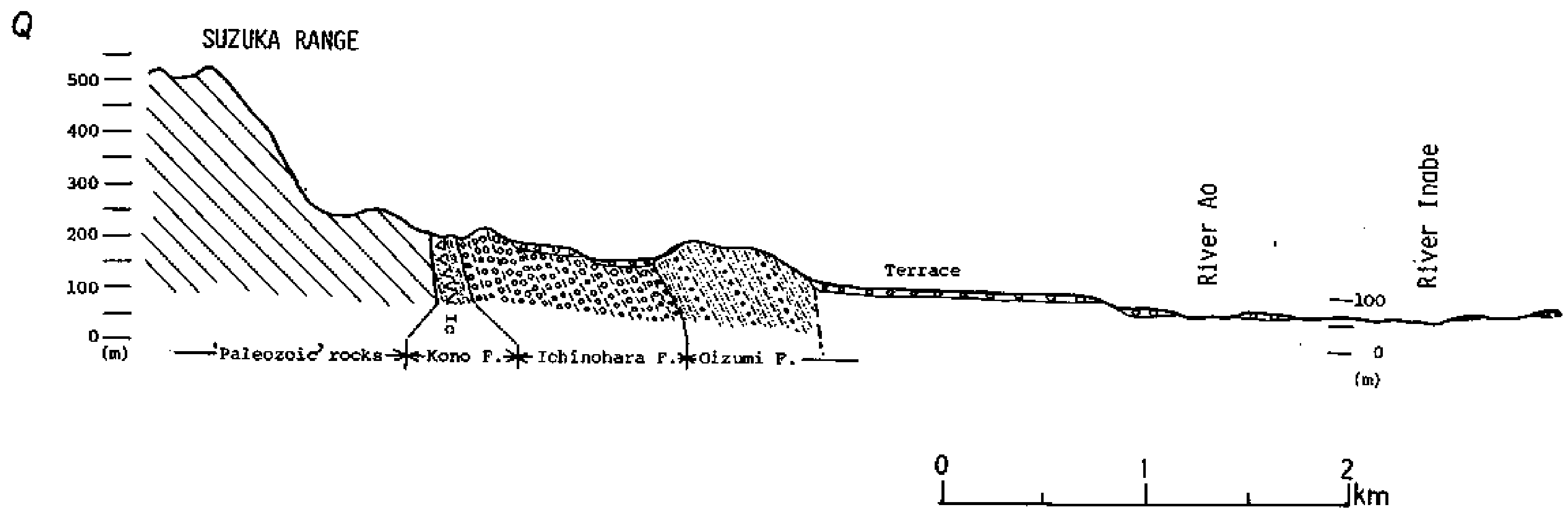


Fig. 14. Geologic profile of the Tokai Group in the foot of the Suzuka Mountains.

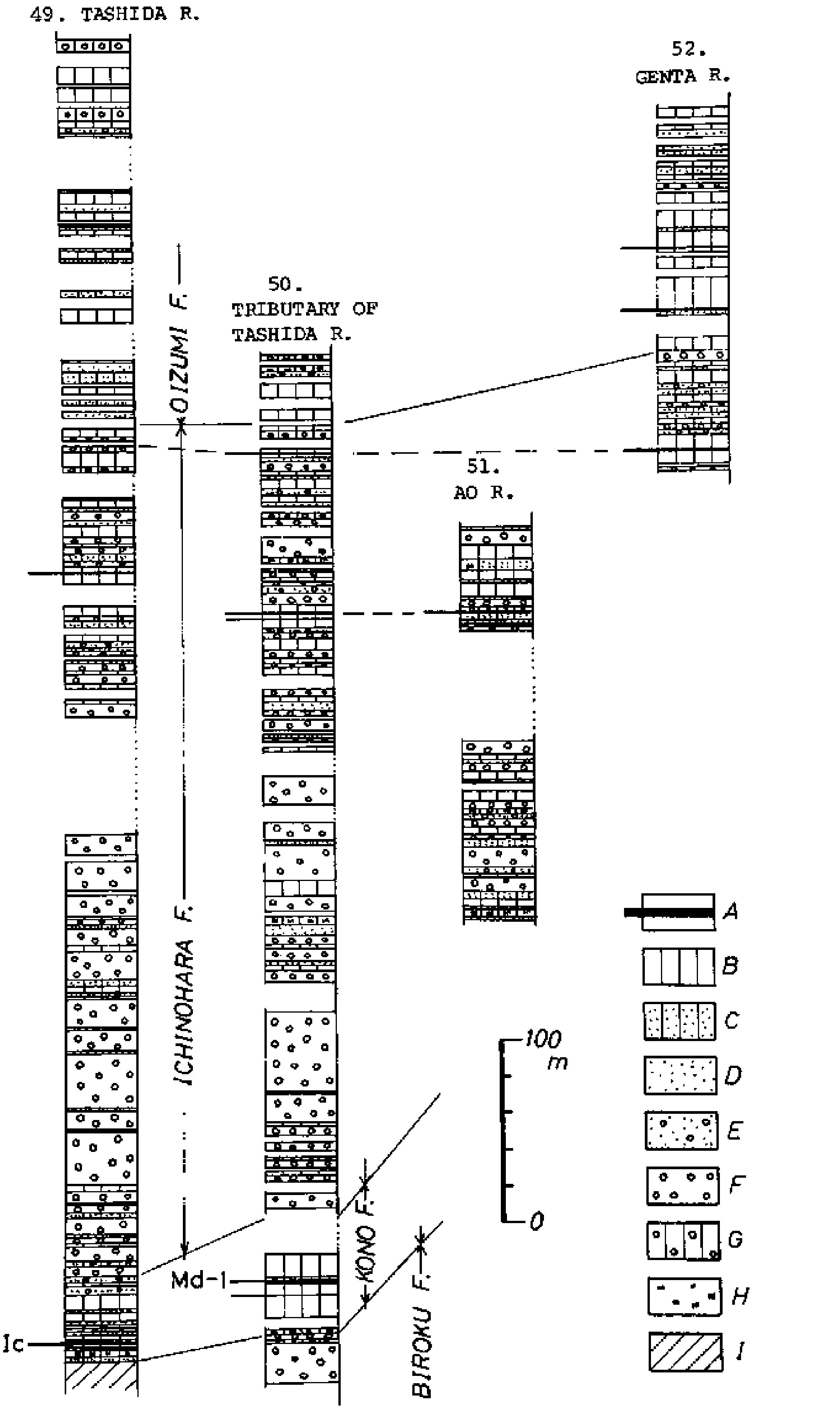


Fig. 15. Columnar sections of the Tokai Group in the foot of the Suzuka Mountains.

lower part is composed mainly of cobble gravels with thin mud layers, and the upper part is composed of alternating beds of gravel and mud.

The Oizumi Formation is also exposed at the cliffs along the Tashida river. It exceeds 220 m in thickness and is composed of alternating beds of sand and mud with some gravel layers.

d. Kuwana area (Fig. 3-D)

In the west of Kuwana City, the Tokai Group forms the hills of 50-200 m in height, and makes an asynmetric anticline in N-S trend, called Kuwana Anticline (Figs. 16 and 17). At the east wing of this anticline, the strata are steeply inclined to Ise Bay. Around the axis of the anticline, the Kono Formation is exposed. To the upper horizon, the Ichinohara, Kuragari and Oizumi Formations are successively arranged in ascending order. The total thickness of the strata is about 420 m (Fig. 18). At least eight volcanic ash layers are found in the east wing of the anticline and fourteen layers in its west wing.

The Kono Formation is exposed at Nishibessho of Kuwana City, and is composed of alternating beds of sand and mud. It is about 30 m thick. At the axis of the Kuwana anticline, a light gray hard volcanic ash layer (Higashidani volcanic ash layer) is observed, and it contains fragments of plant remains.

The Ichinohara Formation exceeds about 100 m thick and is represented by sandy alternation of sands and muds with some pebbly gravel layers. This facies is called "Kuwana

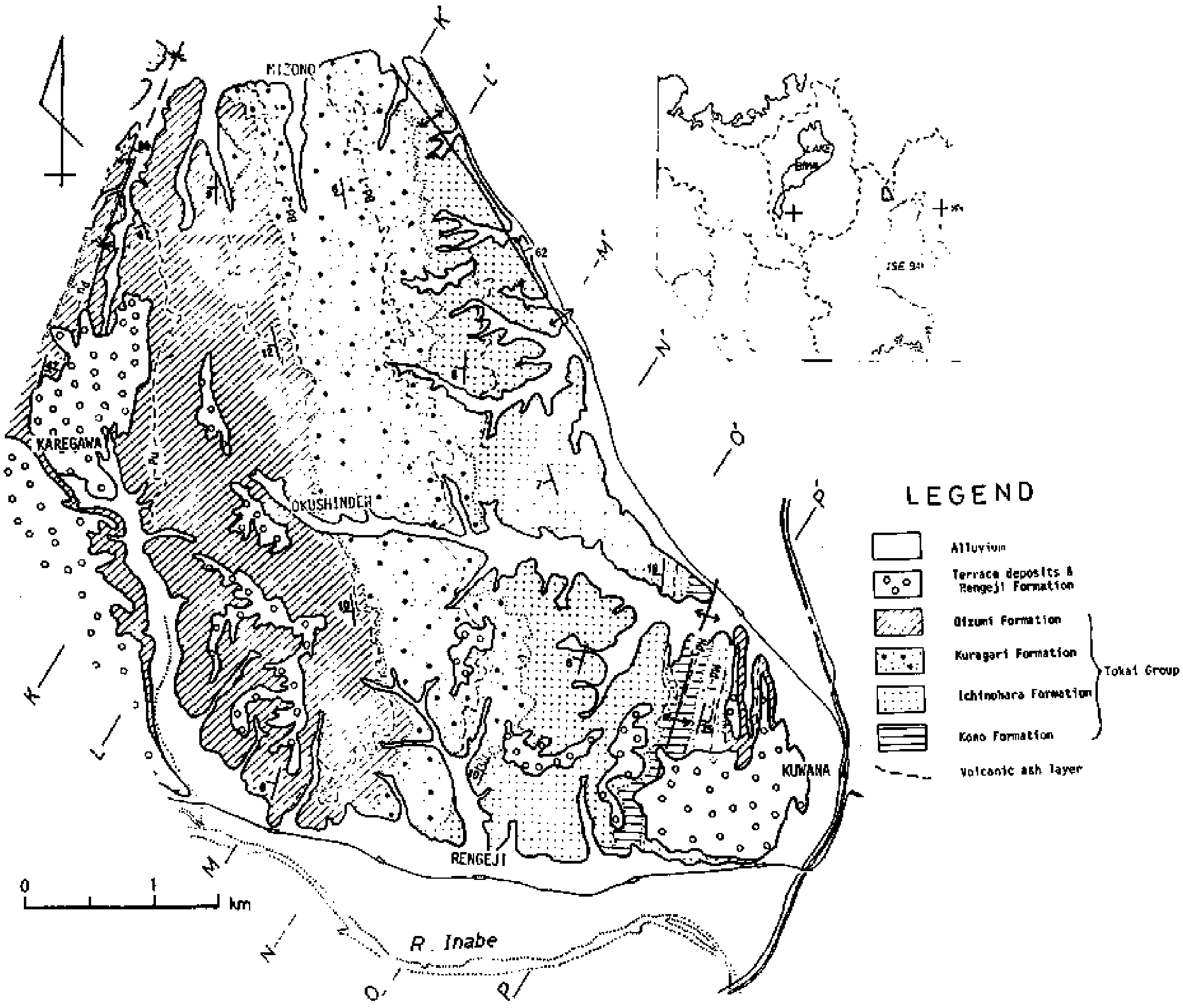


Fig. 16. Geologi⁻ nap of the Tokai Group in the Kuwana area.

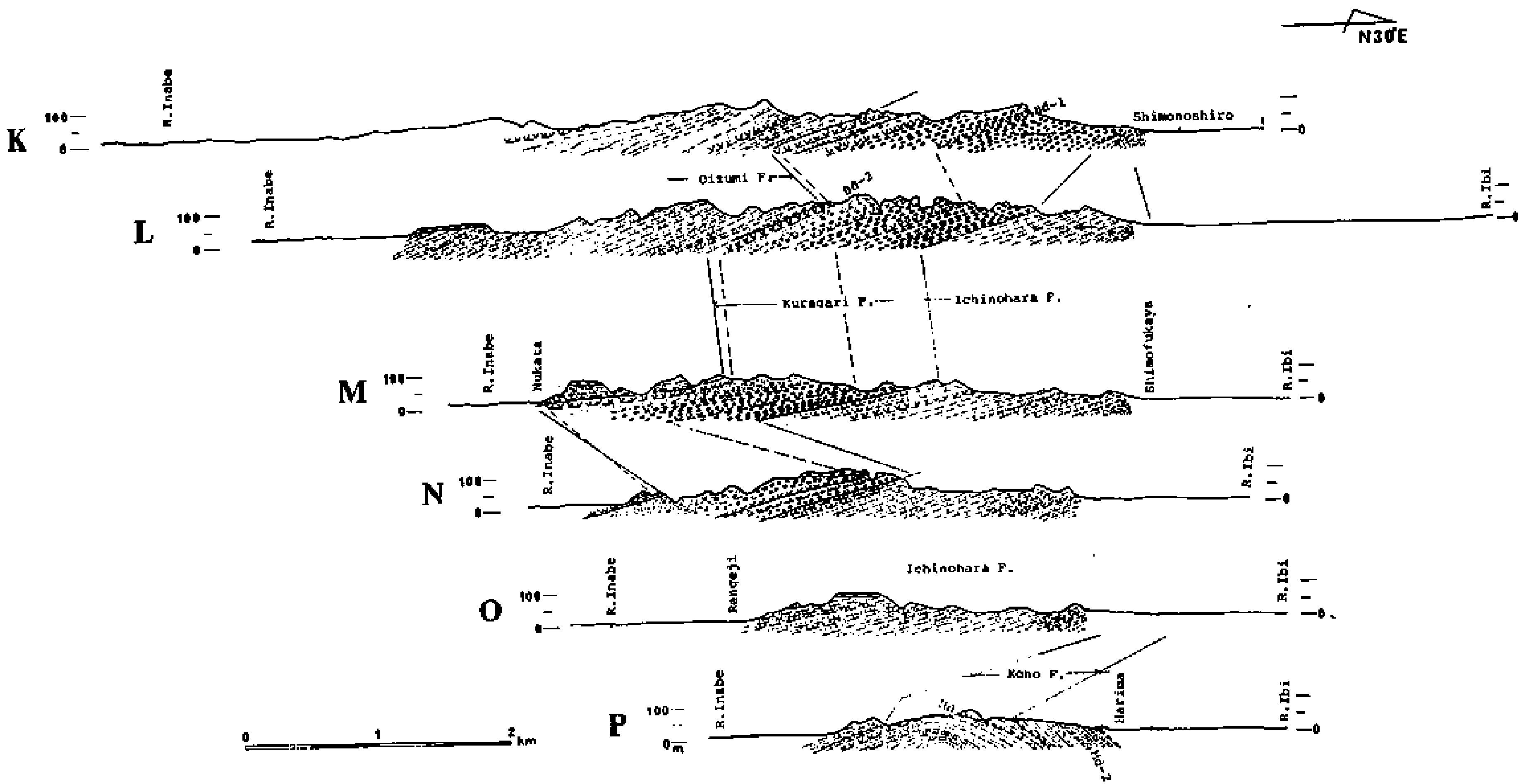


Fig. 17. Geologic profiles of the Tokai Group in the Kuwana area.
(legend: see Fig. 6, profiling lines: see Fig. 16)

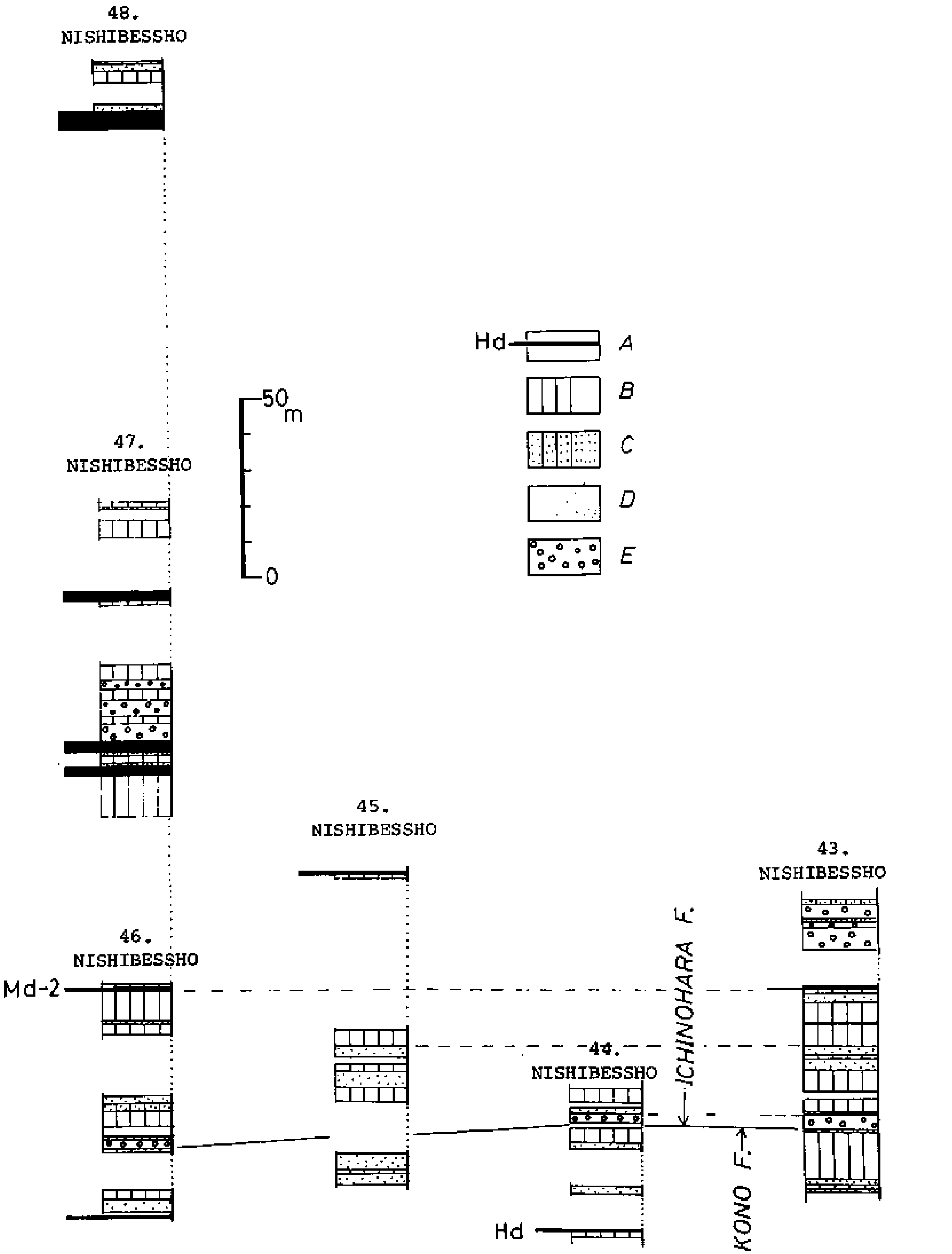


Fig. 18-a. Columnar sections of the Tokai Group in the Kuwana area. (legend: see Fig. 7-b, route No.: see Fig. 4).

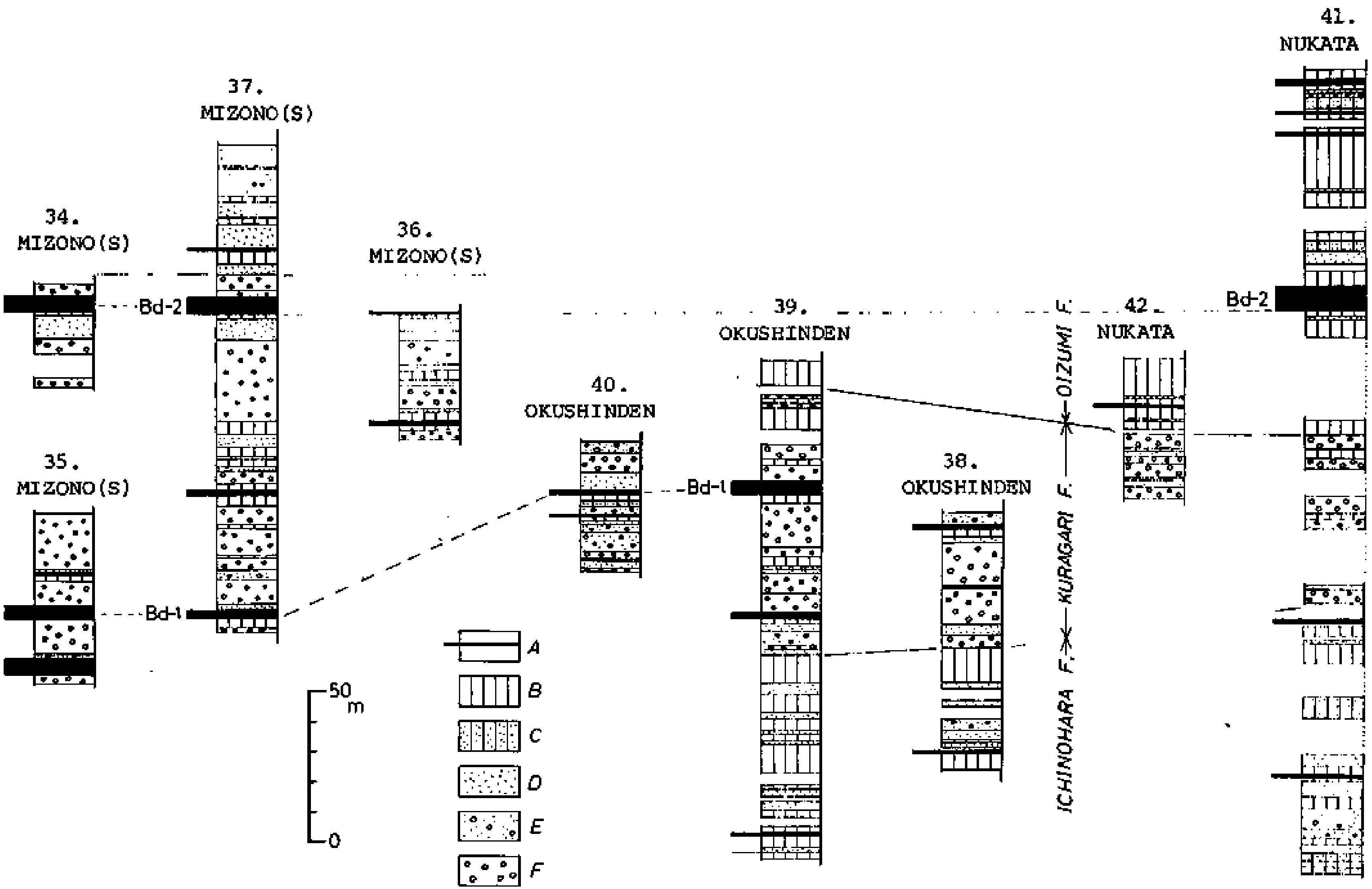


Fig. 18-b. Columnar sections of the Tokai Group in the Kuwana area.
(legend: see Fig. 7-b, route No: see Fig. 4).

facies of the Ichinohara Formation", and is different from that of alternating beds of gravel and mud at the Inabe and Hokusei area. In Sakashitacho of Kuwana City (at the west wing of Kuwana anticline), the Ichinohara Formation (about 70 m thick) are covered with the Kuragari Formation of the gravel facies.

The Kuragari Formation is well exposed at the pilotfarm to the south of Mizono. The sediments is about 140 m in thickness, which is the thickest part of the Kuragari Formation. In Okushinden of Kuwana City, this formation is about 90 m thick. At the cliff facing to south along the way to a feed tank in Oyamada Residence area, the strata of about 40 m in thickness are observed. In its middle part, two volcanic ash layers are intercalated and the upper one is assignable to the Bando-1 volcanic ash layer. At this locality, the Kuragari Formation is unconformably covered with the Middle Pleistocene Rengeji Formation.

The Oizumi Formation in this area, is composed of sandy alternation of sands and muds and is about 120 m thick. Together with very thick (about 10 m) beds of the Pumice volcanic ash layer at Nishibessho and the valley to the east of Karegawa at least six volcanic ash layers are intercalated in this formation. Along the road of Kuwana Chuo Line, the Oizumi Formation is exposed over about 900 m from the Kuwana IC (Interchange) to the west. At the locality about 400 m to the west of the Kuwana IC, a thick (about 10 m) pumiceous volcanic ash layer is intercalated, which contains many pumice grains in the middle part. It can be designated to the Bando-2 volcanic ash layer.

e. Kaki and Oyachi Hills (Fig. 3-E)

Along the west coast of Ise Bay, from Kuwana to Yokkaichi City, there are two hilly regions of about 50-100 m in height, which are composed of the Tokai Group. Among them, the northern hill is called "Kaki Hill" and the southern one is called "Oyachi Hill". As the axis of anticline running from Kuwana hill (Kuwana anticline) plunges to the south, the upper horizon appeared in the southern part alongside the anticline axis (Figs. 19 and 20).

In the Kaki hill, the Tokai Group is divided into the Ichinohara (340 m thick), Kuragari (110 m thick) and Oizumi (260 m thick) Formations in ascending order. Throughout these sequences, at least sixteen volcanic ash layers are identified. In the area around Kuwabe, the Ichinohara Formation is composed mainly of alternating beds of sand and mud with small amount of pebble gravel layers, and it belongs to the Kuwana Facies (Fig. 21). The Kuragari Formation is well exposed along the Higashi Meihan Highway. It is composed mainly of sandy gravel deposits and is similar to the facies around Kuwana City. It contains some volcanic ash and mud layers. The Oizumi Formation is composed of alternating beds of sand and mud with some gravel layers. This facies is slightly different from that in the Kuwana area,

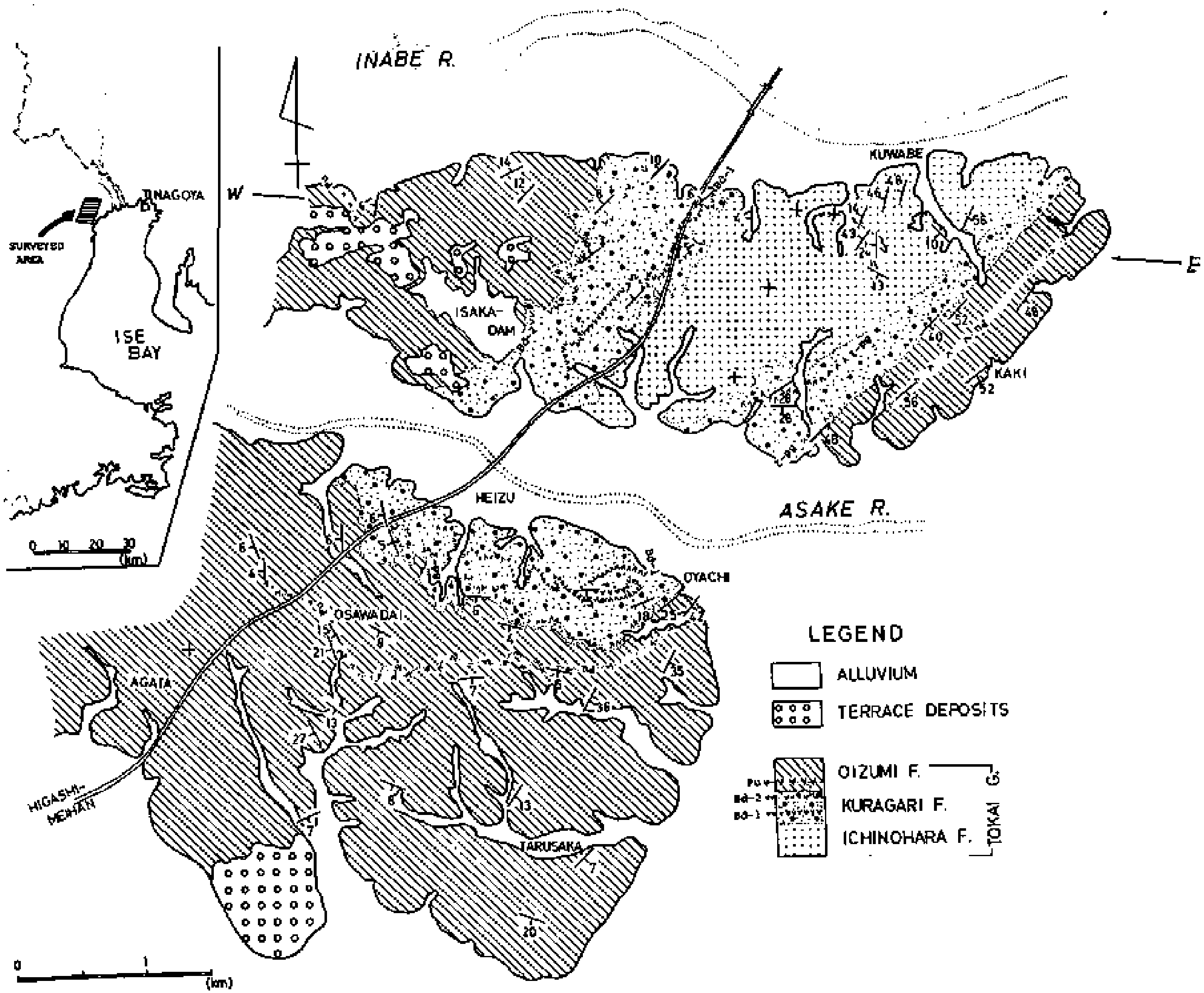


Fig. 19. Geologic map of the Tokai Group in the Kaki and Oyachi areas.

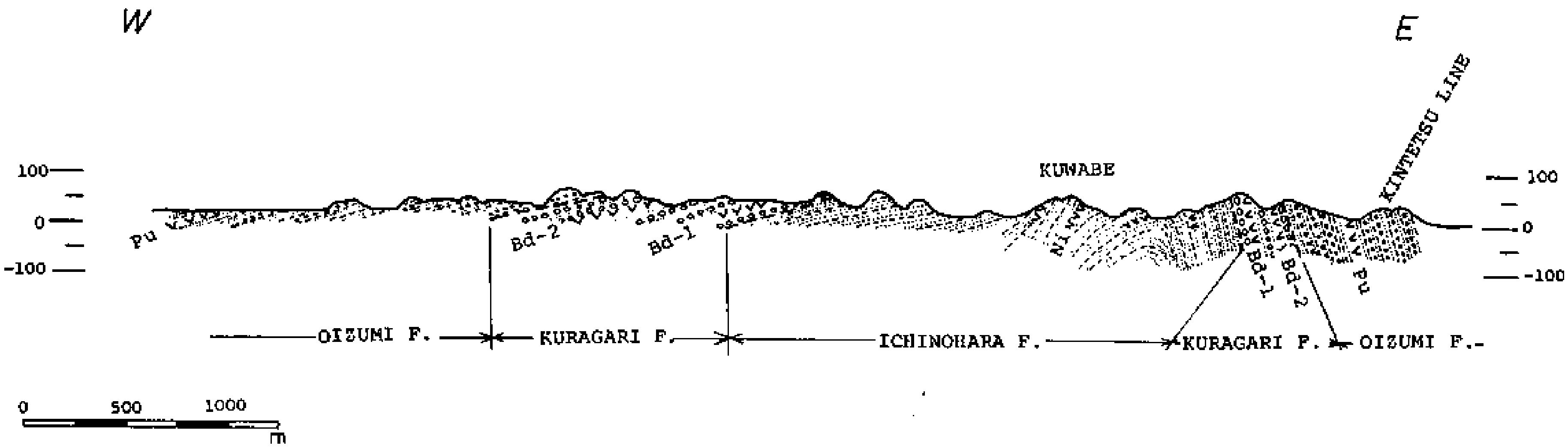


Fig. 20. Geologic profile of the Tokai Group in the Kaki and Oyachi areas.

Fig. 21-a. Columnar sections of the Tokai Group in the Kaki area.
(legend: see Fig. 7-b, route No.: see Fig. 4)

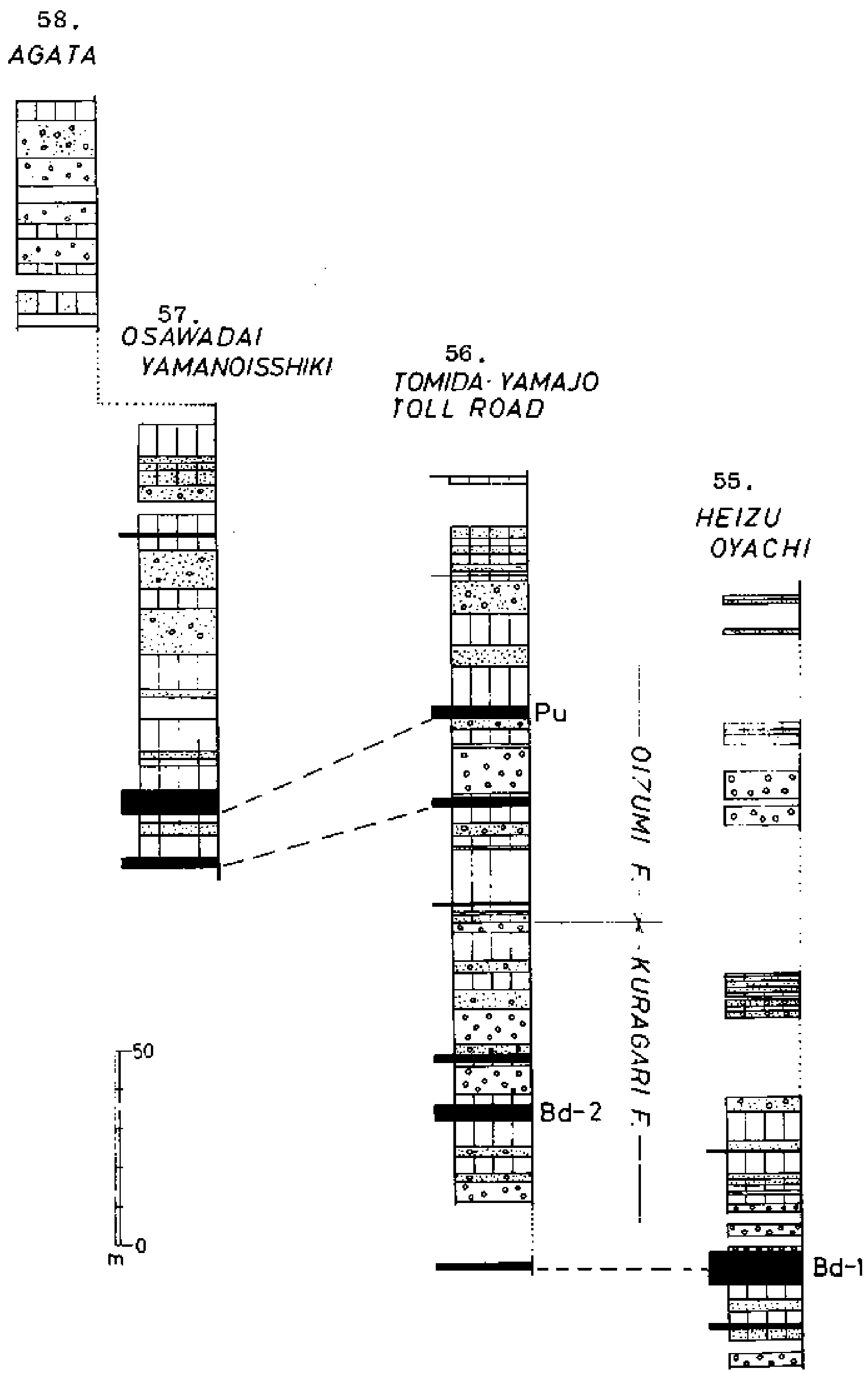


Fig. 21-b. Columnar sections of the Tokai Group in the Oyachi area. (legend: see Fig. 7-b, route No.: see Fig. 4)

because of the presence of large amount of sandy materials and abundant gravel layers (Fig. 21).

In the Oyachi hill, the Tokai Group consists of the Kuragari and Oizumi Formations in ascending order. The former is composed of sandy gravel layers and is about 110 m thick. The Kuragari Formation is exposed at Heizu, west of Oyachi, and in the lowest part, a peculiar volcanic ash layer containing many pumice grains is intercalated. Muddy sediments are more dominant than in the Kuwana area. The Oizumi Formation is about 240 m thick and can be divided into two facies vertically. The upper half is exposed at Tarusaka of southeastern part of the hill and at Agata of western part of the hill. It is composed mainly of sand and gravel layers in which cross laminations are well developed. The lower half which is composed of alternating beds of sand and mud with some gravel layers is observed along the Tomida-Yamajo Toll Road.

f. Yokkaichi area (Fig. 3-F)

The Tokai Group distributed at the west of Yokkaichi City corresponds to the Oizumi Formation in Hokuse area. It is about 150 m thick and is divided into two parts as shown in the geologic map and columnar section of Figs. 22 and 23.

The lower half is about 50 m thick and is composed of alternating beds of bluish gray colored clay and sand with some pebble gravel layers, and is called "Kawashima Member". Those deposits are distributed mainly around Kawashima of

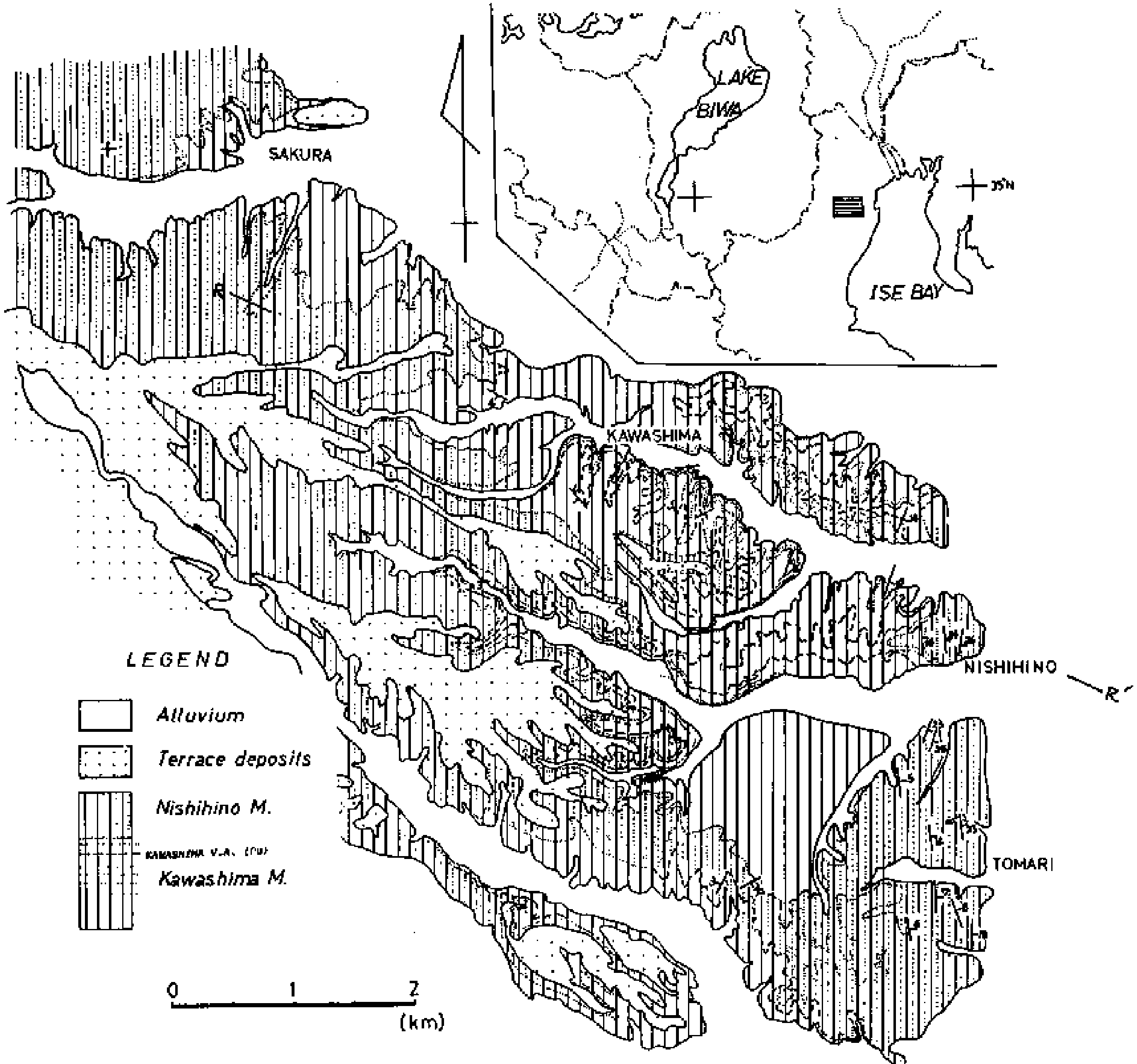


Fig. 22. Geologic map of the Tokai Group in the Yokkaichi area.

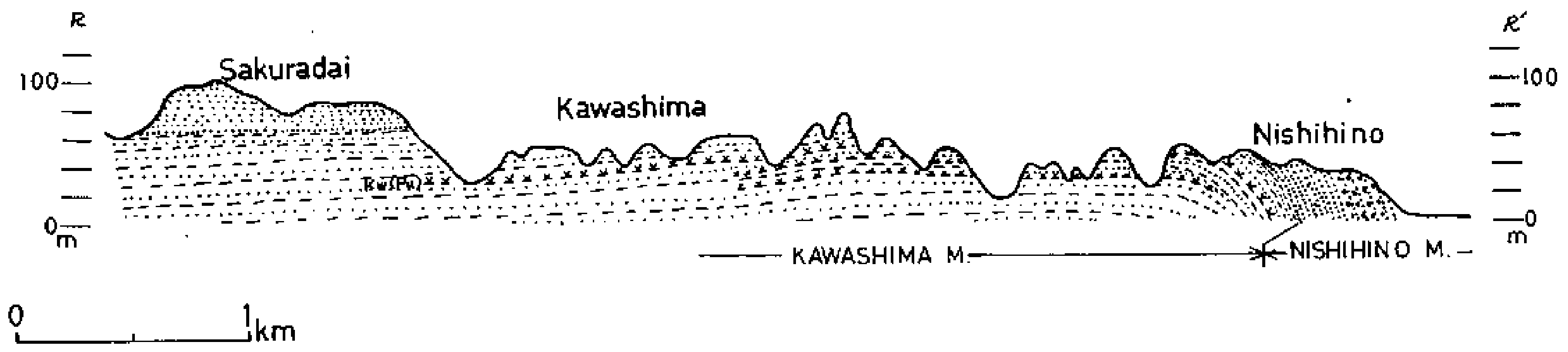


Fig. 23. Geologic profile of the Tokai Group in the Yokkaichi area.

Yokkaichi City. In this member, a prominant volcanic ash layer of about 10 m in thickness is intercalated. This layer treated as very useful key bed in this hill region (Fig. 24) is composed of coarse grained pumiceous ash, and is designated to the Pumice volcanic ash layer. The upper half of about 100 m thick is composed mainly of sand layers with many gravels, and is called "Nishihino Member". Those deposits are distributed at the top of the hill and in eastern end of the hill.

Lithology and relationship between lithofacies and volcanic ash layers in the Hokuse area are summarized in Fig. 25 and Table 2.

D. DESCRIPTION OF VOLCANIC ASH LAYERS

At least thirty volcanic ash layers intercalated in the Tokai Group are discriminated each other in the surveyed area. Among them thirteen are very useful key beds for chrono-stratigraphical and biostratigraphical correlation on the basis of their characteristics and wide distribution, and they will be described in ascending order as follows.

1. Biroku volcanic ash layer (Mori and Kimura, 1973)

Type locality: northwest of Biroku, Tado-cho

This volcanic ash layer of 30 cm in thickness is intercalated in the lower part of the Kono Formation and is composed of massive medium-grained ashes . The color is yellowish green in the weathered part and gray in the fresh part. It contains heavy minerals as hornblende, biotite and apatite. Its NRM (natural remanent magnetization) reveals reversed polarity.

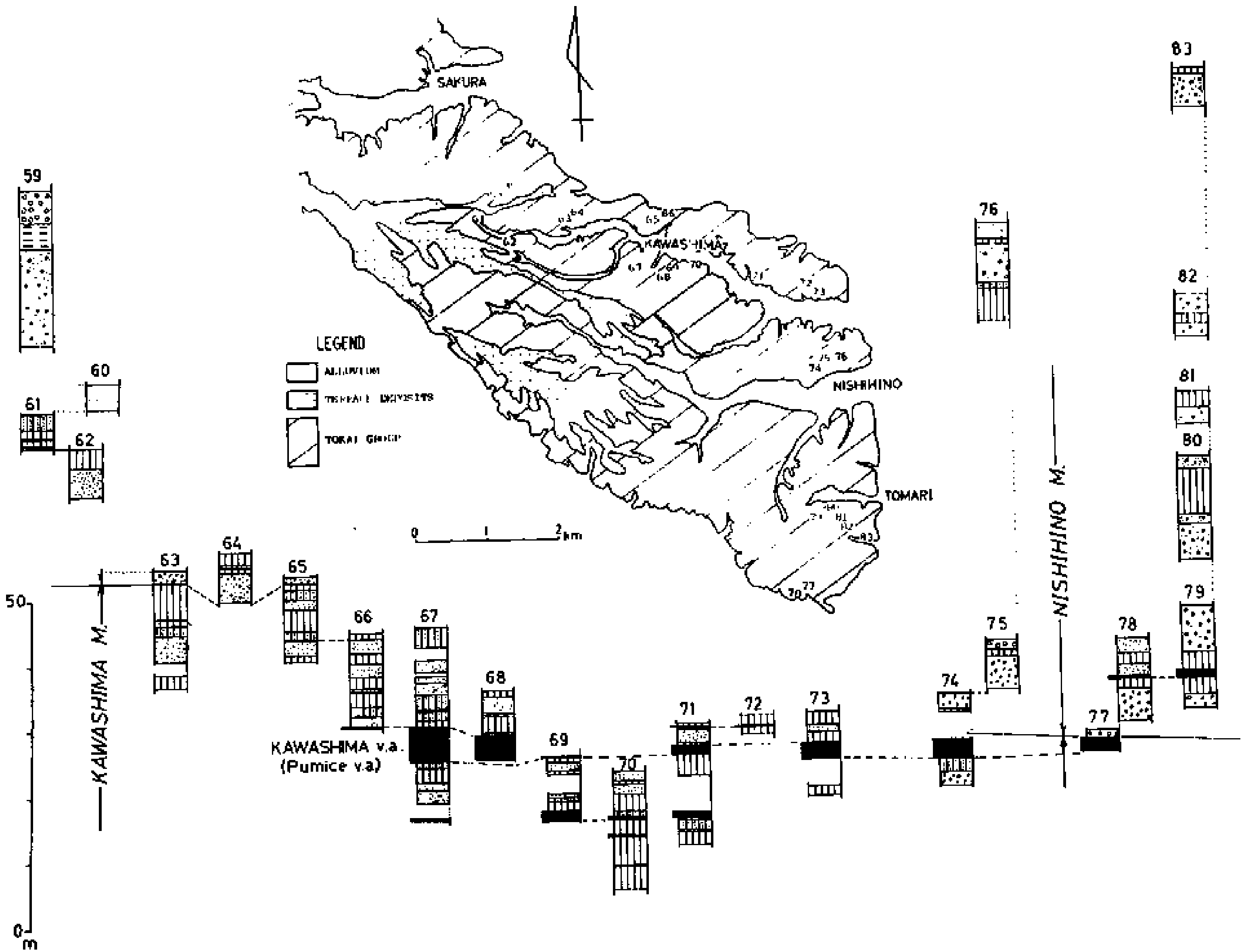


Fig. 24. Columnar sections of the Tokai Group in the Yokkaichi area.

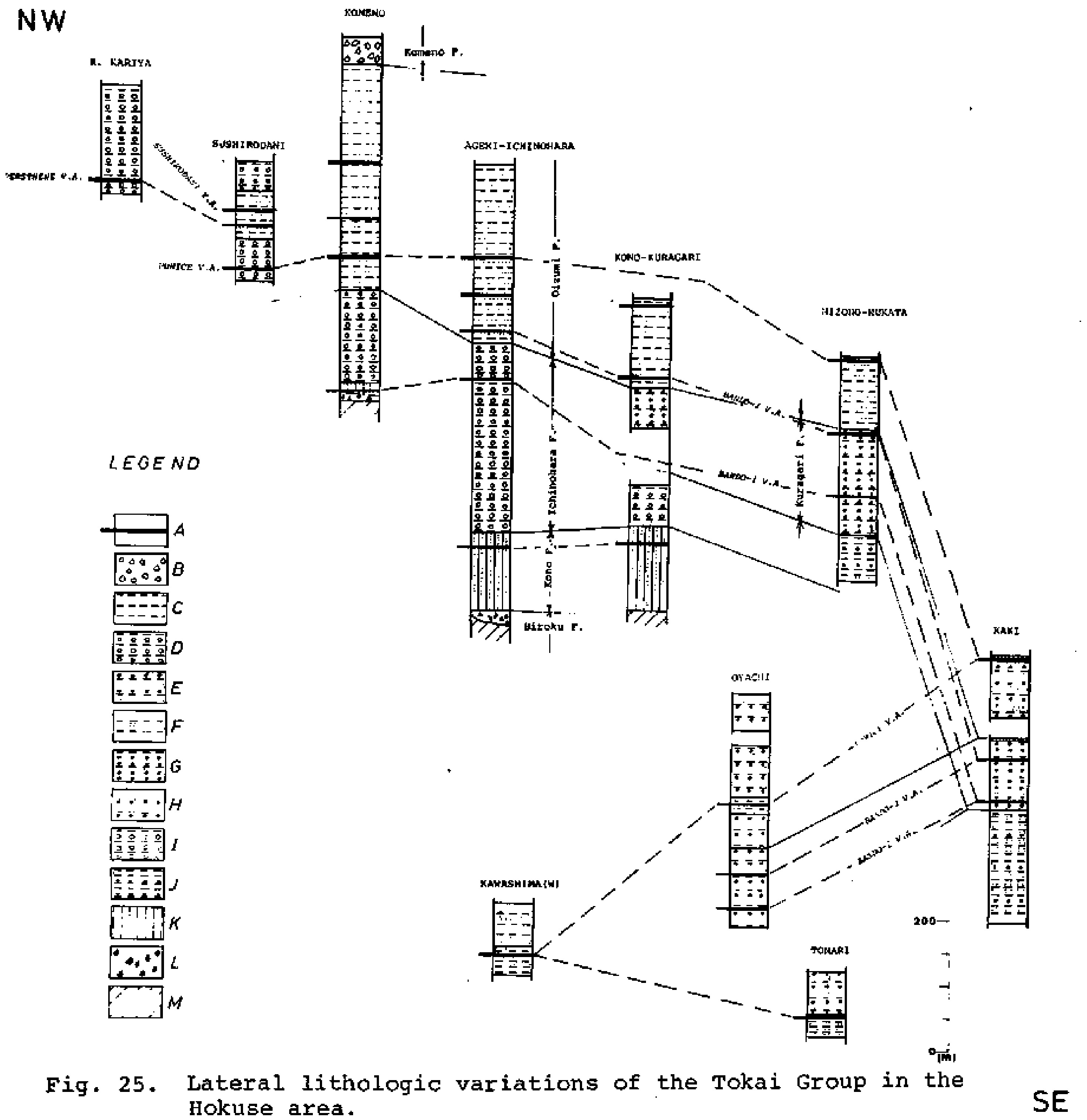


Fig. 25. Lateral lithologic variations of the Tokai Group in the Hokuse area.
A: volcanic ash layer B: gravels of the Komeno Formation C: alternating beds of sand and mud of the Oizumi Formation D: alternating beds of mud and gravel of the Oizumi Formation E: sand and gravels of the Oizumi Formation F: sand dominant alternating beds of sand and mud of the Oizumi Formation G: sand and gravel of the Kuragari Formation H: sand dominant alternating beds of sand and gravel of the Kuragari Formation I: alternating beds of mud and gravel of the Ichinohara Formation J: alternating beds of mud and sand of the Ichinohara Formation K: alternating beds of mud and sand of the Kono Formation L: gravels of the Biroku Formation M: Mesozoic and Paleozoic formations.

Although other two volcanic ash layers are observed below this at the type locality, their NRMs show reversed polarity.

2. Higashidani volcanic ash layer

Type locality: Higashidani in the east of Icninohara, Inabe-cho

This volcanic ash layer is intercalated in the middle part of the Kono Formation. It is situated at the horizon about 40 m high above the Biroku volcanic ash layer. Thickness is 50 cm at the type locality. It is pale in color in fresh part, and is yellow-greenish gray in weathered part. Its NRM reveals normal polarity. This layer is also exposed at the riverbed of the Hijie river and at Nishibessho, containing well-preserved fossil leaves. Once it was correlated with the Biroku volcanic ash layer (Mori and Kimura, 1973), but it is clear that this volcanic ash layer is different from the Biroku volcanic ash layer from the stratigraphic position and magnetic polarity.

3. Ichinohara volcanic ash layer

Type locality: At the pass along the road from Ichinohara to Biroku, Inabe-cho

This volcanic ash layer is intercalated in the upper part of the Kono Formation. Its thickness is 86 cm at the type locality. Within it, three different parts are observed as shown in Fig. 26. The lowest part is dark gray in color, and is composed of coarse-grained volcanic glasses with crystals of biotite and quartz and small pumice grains. The middle

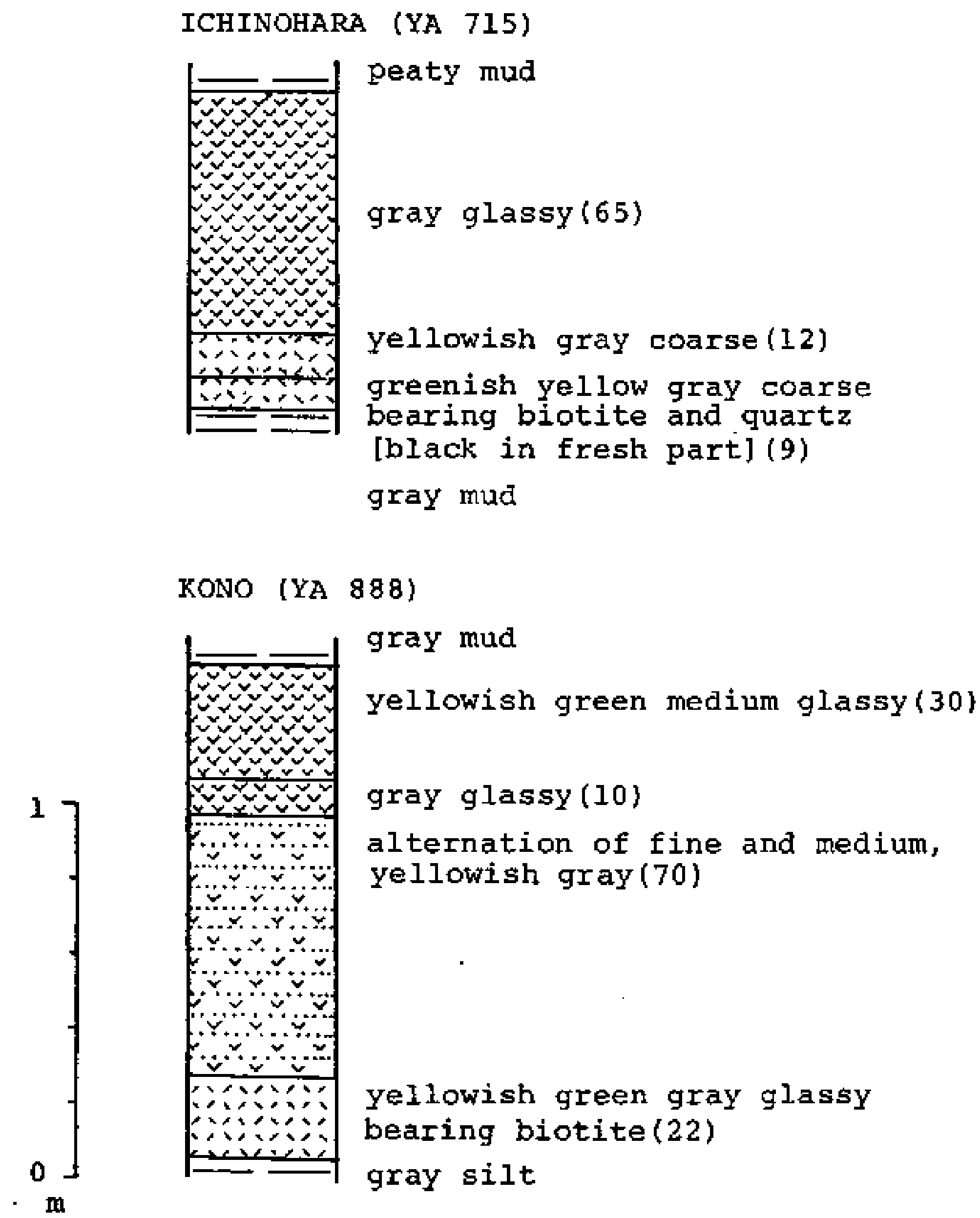


Fig. 26. Columnar sections of the Ichinohara volcanic ash layer.

part is greenish yellow in color, and is composed of coarse-grained volcanic glasses with biotite crystals. The upper part is composed mainly of glass flakes, and is light gray in color. It contains heavy minerals such as biotite, hornblende, orthorhombic pyroxene and zircon. Its NRM shows normal polarity. The fission-track ages were measured at two localities respectively; 2.8 m.y. for the sample at Kono-minamidani and 2.9 m.y. at the Tashida river (Yokoyama et al., 1980b).

4. Minamidani-1 volcanic ash layer

Type locality: Minamidani in the south of Kono, Tado-cho

This volcanic ash layer is intercalated in the lower part of the Ichinohara Formation. Its thickness is about 80 cm at the type locality. Within it, two different parts can be observed. The lower part is composed of fine glassy volcanic ash and yellow in color. It contains heavy minerals such as hornblende, orthorhombic pyroxene, clinopyroxene, biotite and apatite. Its NRM reveals normal polarity.

5. Minamidani-2 volcanic ash layer

Type locality: Minamidani in the south of Kono, Tado-cho

This volcanic ash layer is intercalated in the horizon of 40 m above the Minamidani-1 volcanic ash layer. Its thickness is 90 cm at the type locality. The lower part is greenish yellow in color, and is composed of medium-grained glass flakes. On the other hand, the upper part is composed of alternating beds of fine- and medium-grained glassy layers. It contains heavy minerals such as hornblende, orthorhombic pyroxene and biotite. Its NRM reveals normal polarity.

6. Ninose volcanic ash layer

Type locality: at Ninose, Hokusei-cho

This volcanic ash layer is intercalated in the middle part of the Ichinohara Formation. This massive glassy volcanic ash layer is light gray in color. At the type locality, it is 40 cm thick and is intercalated in gray muds. Its NRM reveals reversed polarity.

7. Otsujishinden volcanic ash layer

Type locality: at riverbed of the Yamada river in the east of Otsujishinden, Hokusei-cho

This volcanic ash layer is situated in the upper part of the Ichinohara Formation, in the horizon about 110 m above the Ninose volcanic ash layer. Its thickness is 95 cm at the type locality and is divided into three parts. The lower part is 2-5 cm thick, coarse-grained glassy volcanic ash, and white in color. The middle part, about 35 cm thick, consists of laminated fine volcanic ash with small pumice grains, and is very hard. The upper part, about 55 cm thick, is massive and pale gray in color. In this part, small pumice grains and plant fragment are contained.

8. Bando-1 volcanic ash layer

Type locality: North of Bandoshinden, Inabe-cho

This volcanic ash layer is generally intercalated in the upper part of the Ichinohara Formation. Also it is in the Kuragari Formation in the eastern part of the Hokusei and Inabe area, and Kuwana area. Its thickness is 200 cm at the type locality, and it reaches to 400 cm in the east of Ichinohara. This volcanic ash layer is divided into two parts. The lower part is medium-grained pumiceous ashes and pale yellow in color. The upper part is composed of the alternating beds of fine and medium-grained ashes. It contains many pumice grains. Its NRM shows reversed polarity. At the type locality, this volcanic ash layer seems to be coincidental with the T_8 of Takehara (1961).

9. Bando-2 volcanic ash layer

Type locality: Higashikoyamadani, Hokusei-cho

This volcanic ash layer is intercalated in the lowermost part of the Oizumi Formation. Its thickness is 160 cm at the type locality, but it reaches upto 1,000 cm at Nukata in Kuwana City. This ash layer is massive and pale gray in color, and contains abundant pumice grains. This is composed mainly of glass flakes with heavy minerals such as orthorhombic pyroxene, hornblende, biotite, apatite and zircon. Its NRM reveals reversed polarity.

10. Sonohara volcanic ash layer

Type locality: at riverbed of the Yamada river in the east of Sonohara, Hokusei-cho

This volcanic ash layer is intercalated in the lower part of the Oizumi Formation, and about 50 m below the horizon of the Pumice volcanic ash layer. Its thickness is 60 cm at the type locality. The middle part is composed of coarse-grained volcanic ash layer with abundant pumice grains. The color is is dark gray. Such heavy minerals as hornblende, orthorhombic pyroxene, clinopyroxene, biotite and apatite are contained, but glass flakes are very rare.

11. Pumice volcanic ash layer (Yokoyama, 1971)

Type locality: Nishikaino, Hokusei-cho

This volcanic ash layer is intercalated in the middle part of the Oizumi Formation. This layer can be traced continuously from Kamitara in Gifu Prefecture, and through Kamikasada and Karegawa, to Yokkaich City. Its thickness is 700 cm at the type locality, but it reaches to 1,300 cm at the riverbed of the Akechi river. This layer is divided into three parts as shown in Fig. 27. The lower part is very hard and massive with laminated part. The middle part is composed of coarse-grained volcanic sand with many pumice grains, and is white in color. In addition, cross-laminations are observed in this part. The maximum size of pumice grain is generally 5-6 cm in diameter. The upper part is fine-grained, laminated and white in color. It contains heavy minerals such as hornblende, orthorhombic pyroxene, clinopyroxene and apatite. Its NRM reveals reversed polarity. The Pumice volcanic ash layer has been treated as an useful key bed, and it is correlated with the Mushono volcanic ash layer of the Kobiwako Group (Yokoyama, 1969; Ishida and Yokoyama, 1969).

12. Sushirodani volcanic ash layer(Miyamura et al., 1976)

Type locality: Sushirodani valley at the east of Kanae, Fujiwara-cho

This volcanic ash layer is intercalated in the middle part of the Oizumi Formation. It is 20-80 cm thick. The

NISHIKAINO (YA 63)

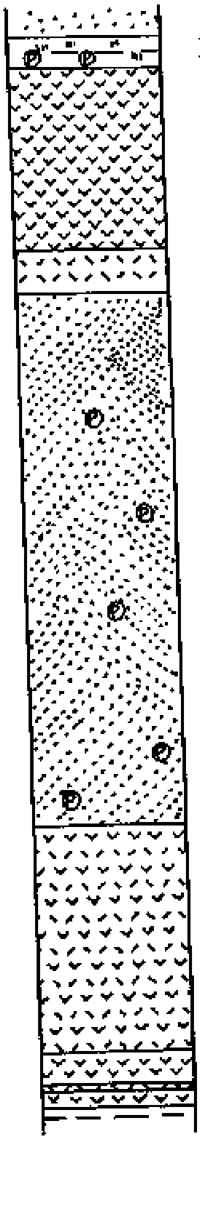


Fig. 27. Columnar section of the Pumice volcanic ash layer.

lower part is 5-7 cm thick and is yellowish gray in color. It is composed of small pumice grains (diameter; less than 1 mm) and hornblende crystals, in which the latters are usually visible even by naked eyes. The upper part is composed of fine grained volcanic glass flakes and is yellowish white and pinkish white in color.

13. Rokkoku volcanic ash layer (Mori and Kimura, 1973)

Type locality: West of Rokkoku, Hokusei-cho

This volcanic ash layer is intercalated in the upper part of the Oizumi Formation. Its thickness is 55 cm at the type locality. It is composed of medium-grained glassy volcanic ash and is white to pale yellow in color. Its NRM shows reversed polarity. The fission track age of this ash layer at the type locality is measured 1.4 m.y. (Yokoyama et al., 1980b).

Although this was recently confirmed to be same to the Komeno II volcanic ash layer of Yokoyama (1971), the name of the Rokkoku volcanic ash layer is used in this paper conveniently.

E. BIOSTRATIGRAPHY, MAGNETOSTRATIGRAPHY AND FISSION TRACK AGES

In the Plio-Pleistocene sediments of the Kinki and Tokai districts, Miki (1948) recognized first six fossil plant beds. Those are <u>Pinus trifolia</u> bed, <u>Metasequoia</u> bed, <u>Paliurus</u> bed, <u>Larix</u> bed, <u>Sapium</u> bed and <u>Aphanante</u> bed in ascending order, and Huzita (1954) confirmed the stratigraphical position of those plant beds. Based on those results, Itihara(1960) discussed the distinction between "the age of <u>Metasequoia</u> flora flourish" and "the age of Metasequoia flora extinction".

Makiyama (1938) studied fossil elephants from those districts, and Ikebe et al. (1966) made check list of their stratigraphical positions and localities. Then, Kamei and Setoguchi (1970) recognized five fossil zones of Pliocene-Pleistocene mammals. Those are Zone 1 of Stegodon cf. elephantoides, Zone 2 of Stegodon insignis sugiyamai, Zone 3 of Stegodon shodoensis akashiensis, Zone 4 of Elephas shigensis and Zone 5 of Stegodon orientalis.

In the Pliocene-Pleistocene Tokai Group, many fossils such as plants, vertebrates, molluscs are also yielded. The horizon of those fossils in the Hokuse area are given in Fig. 28. Metasequoia was discovered thoroughout this group, with typical Tertiary flora including Nyssa and Liquidambar in the lower half. Fossil materials of Stegodon cf. elephantoides were found in the Kameyama Formation in the Nanse area, and those of Stegodon akashiensis were reported from the Oizumi Formation in the Hokuse area. Consequently, it is able to say that the Tokai Group is allocated the the Metasequoia bed of Miki(1948), and ranges from Stegodon cf. elephantoides Zone to Stegodon akashiensis Zone biostratigraphically.

The pioneer work on paleomagnetism of the Tokai Group was carried out by Ishida et al. (1969). Maenaka et al. (1977) summarized magnetostratigraphy of the Pliocene-Pleistocene sequences in the Kinki and Tokai districts, together with other geological and paleontological data, but as for the Tokai Group those data were left to be fragmental. Sofar, the author tried

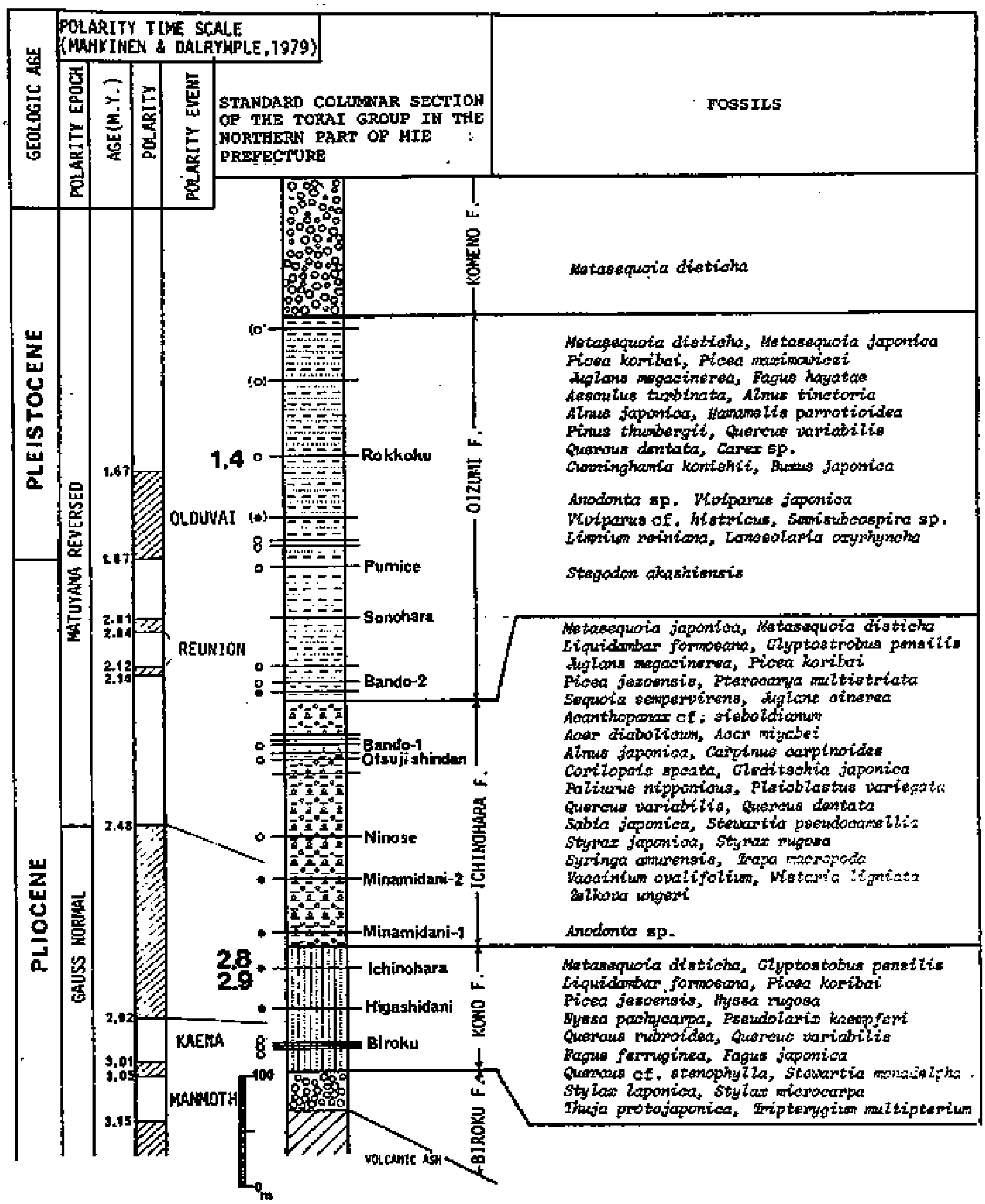


Fig. 28. Chronology of the Tokai Group in the Hokuse area.

and succeeded in measuring NRMs of the volcanic ash layers along seven routes in the foothill area of the Yoro Mountains where continuous columnar sections were obtained (Table 4 and Fig. 29). As the results, it is evident that all of ash layers above the Minamidani-2 volcanic ash layer horizon reveal reversed polarity except for normal polarity of unnamed ash layer immediately below the Bando-2 volcanic ash layer. On the other hand, the ash layers between the Minamidani-2 and the Higashidani reveal normal polarity, but those below the Higashidani reveal reversed polarity again (Takemura and Torii, 1978).

For the fission track age, those of three volcanic ash layers of the Tokai Group were obtained by Yokoyama et al. (1980). The results are as follows:

Ichinohara volcanic ash layer at Kono (loc. YA 888) 2.9±0.3 m.y.
Ichinohara volcanic ash layer at the Tashida river (loc. SA91) 2.8±0.3 m.y.
Rokkoku volcanic ash layer at Rokkoku (loc. YA 72) 1.4±0.2 m.y.

Taking those results into consideration, the deposition of the Tokai Group in the Hokuse area is able to be correlated with the magnetic time scale of Mankinen and Dalrymple (1979), as the upper half assignable to the Matuyama Reversed Epoch, and the lower half corresponding to the Gauss Normal Epoch. Therefore, the reversed polarity zone of the lowest part may be represented by the Kaena event in the Gauss Normal Epoch as shown in Fig. 28. In this way, it is possible to say that the deposition of the Tokai Group in Hokuse area was initiated

Table 4. Paleomagnetic result of volcanic ash layers (Takemura & Torii, 1978).

Sample No.	Locality No.	Locality	Volcanic ash layer	Magnetic polarity
A-9	YA 1358	Mukohira	unnamed	R
A-11	YA 1359	Mukohira	Pumice v.a.	R
A-12	YA 1359	Mukohira	Pumice v.a.	R
A-13	YA 63	Nishikaino	Pumice v.a.	R
A-1	YA 1412	Kawahara	unnamed	R
A-2	YA 1412	Kawahara	unnamed	R
A-5	YA 1412	Kawahara	Bando-1 v.a.	R
A-6	YA 1412	Kawahara	Bando-1 v.a.	R
A-7	YA 1357	Ninose	Ninose v.a.	R
A-8	YA 1357	Ninose	Ninose v.a.	R
A-14	YA 67	Koharaisshiki	Ichinohara v.a.	—
A-15	YA 67	Koharaisshiki	Ichinohara v.a.	N
A-21	YA 72	Nishikoyamadani	Rokkoku v.a.	R
A-16	YA 96	Higashikoyamadani	unnamed	R
A-17	YA 109	Higashikoyamadani	unnamed	R
A-18	YA 111	Higashikoyamadani	Pumice v.a.	R
A-19	YA 120	Higashikoyamadani	unnamed	R
A-20	YA 121	Higashikoyamadani	Bando-2 v.a.	R
A-22	YA 289	N.Bandoshinden	Bando-2 v.a.	R
A-25	YA 58	N.Bandoshinden	unnamed	—
A-24	YA 58	N.Bandoshinden	unnamed	—
A-23	YA 58	N.Bandoshinden	Bando-1 v.a.	R
A-26	YA 291	N.Bandoshinden	unnamed	R
A-27	YA 419	S.Ichinohara	Ninose v.a.	—
A-28	YA 419	S.Ichinohara	Ninose v.a.	R
A-29	YA 715	N.Ichinohara	Ichinohara v.a.	N
A-30	YA 715	N.Ichinohara	Ichinohara v.a.	—
A-31	YA 643	Biroku	Biroku v.a.	R
A-32	YA 643	Biroku	Biroku v.a.	R
A-33	YA 643	Biroku	Biroku v.a.	R

Sample No.	Locality No.	Locality	Volcanic ash layer	Magnetic polarity
A-36	YA 846	Konominamidani	Minamidani-2 v.a.	N
A-35	YA 845	Konominamidani	Minamidani-1 v.a.	N
A-37	YA 811	Konominamidani	Ichinohara v.a.	N
A-34	YA 781	Kono	Biroku v.a.	R
A-44	YA 981	Chikarao	Pumice v.a.	R
A-39	YA 977	Chikarao	unnamed	R
A-40	YA 977	Chikarao	Bando-2 v.a.	R
A-42	YA 1026	Chikarao	Minamidani-1 v.a.	N
A-43	YA 1015	Chikarao	Minamidani-1 v.a.	N
A-41	YA 1025	Chikarao	Ichinohara v.a.	N
A-38	YA 979	Chikarao	Ichinohara v.a.	N
A-45	YA 1449	Nukata	unnamed	R
A-46	YA 1449	Nukata	unnamed	R
A-47	YA 1450	Nukata	unnamed	R
A-48	YA 1461	Nukata	Bando-2 v.a.	R
A-49	YA 1076	Nukata	unnamed	N
A-50	YA 1161	Okushinden	Bando-1 v.a.	—
A-51	YA 1133	Nishibessho	Pumice v.a.	R
A-52	YA 1422	Nishibessho	Bando-2 v.a.	R
A-53	YA 1422	Nishibessho	Bando-1 v.a.	R
A-54	YA 1422	Nishibessho	unnamed	R
A-56	YA 1484	Nishibessho	Minamidani-2 v.a.	N
A-55	YA 1137	Nishibessho	Higashidani v.a.	N
A-57	SA 91	River Tashida	Ichinohara v.a.	N

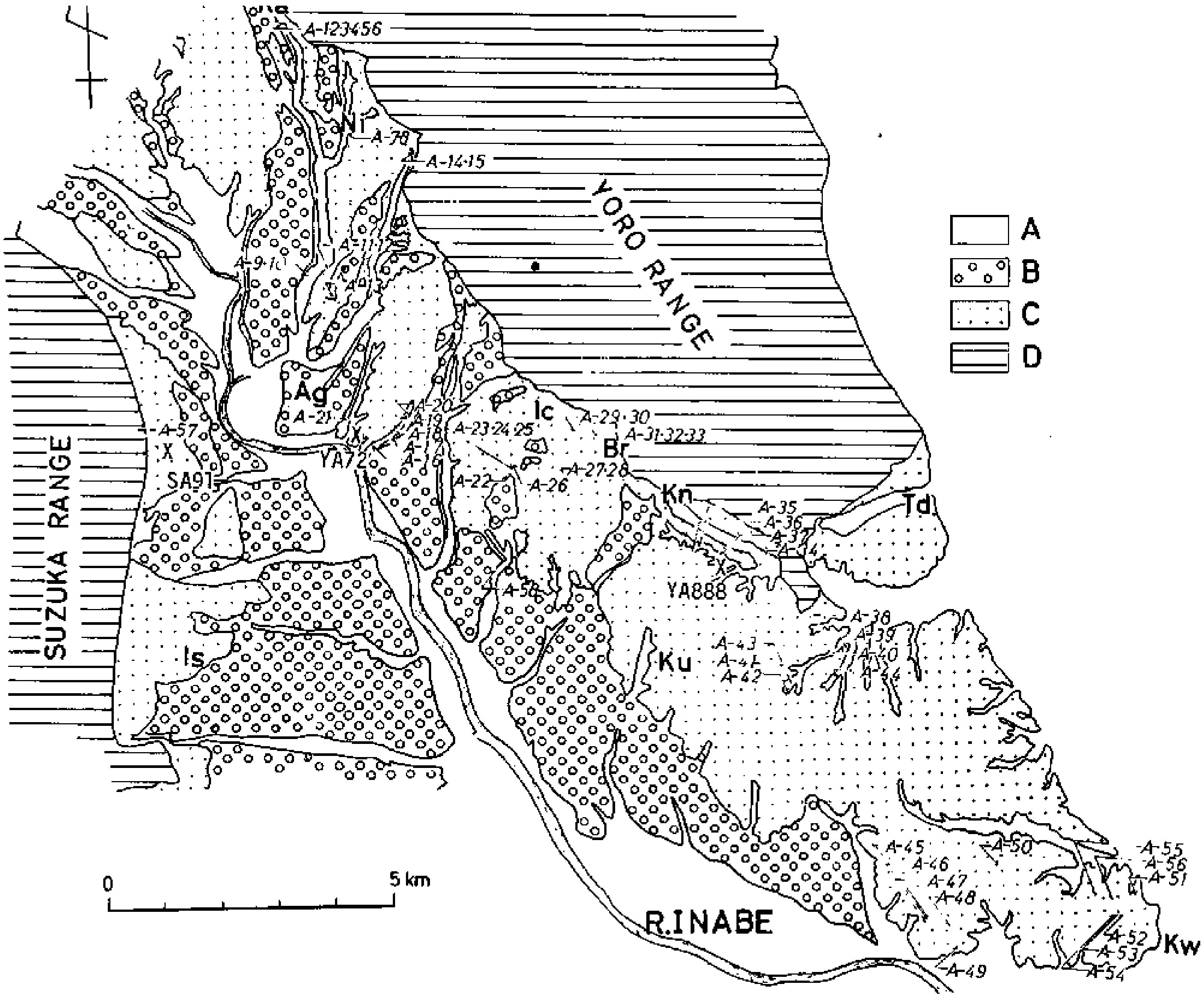


Fig. 29. Locality map of the sampling for fission-track age determination and paleomagnetic research. A: Alluvium, B: Terrace deposits, C: Tokai Group D: Basement rocks

at about 3.0 m.y. B.P. On the other hand, based on the fission track age of the Rokkoku volcanic ash layer and magnetostratigraphical evidences, the upper limit of that deposition can be estimated to be about 1.2 m.y. B.P.

In conclusion, it becomes clear that the deposition of the Tokai Group in the Hokuse area had started from 3.0 m.y. B.P. and terminated at about 1.2 m.y. B.P.

F. GEOLOGIC STRUCTURE

It is well known that Southwest Japan is divided tectonically into "Inner zone" and "Outer zone" by the "Median Tectonic Line", but from viewpoint of neotectonism, the eastern part of the "Inner zone" is further subdivided into such three tectonic provinces as Chubu, Kinki and Chugoku Blocks from east to west. Among them, the Kinki Block reveals a triangular plan as named as "Kinki Triangle" by Huzita (1962). Demarcation of the Kinki Block with the Chubu one is represented by the Yanagase Fault and its southern extension of the Yoro-Ise Bay Fault.

The depression around Ise Bay was the area of Lake Tokai during Pliocene to Early Pleistocene, and is divided into two parts, western and eastern, by the Yoro-Ise Bay Fault (Fig. 30). In this paper, its western half is called the "Agė subbasin" and the eastern half is called the "Nagoya subbasin", but it should be noted that the former belongs to the Kinki Block, while the latter belongs to the Chubu Block. The

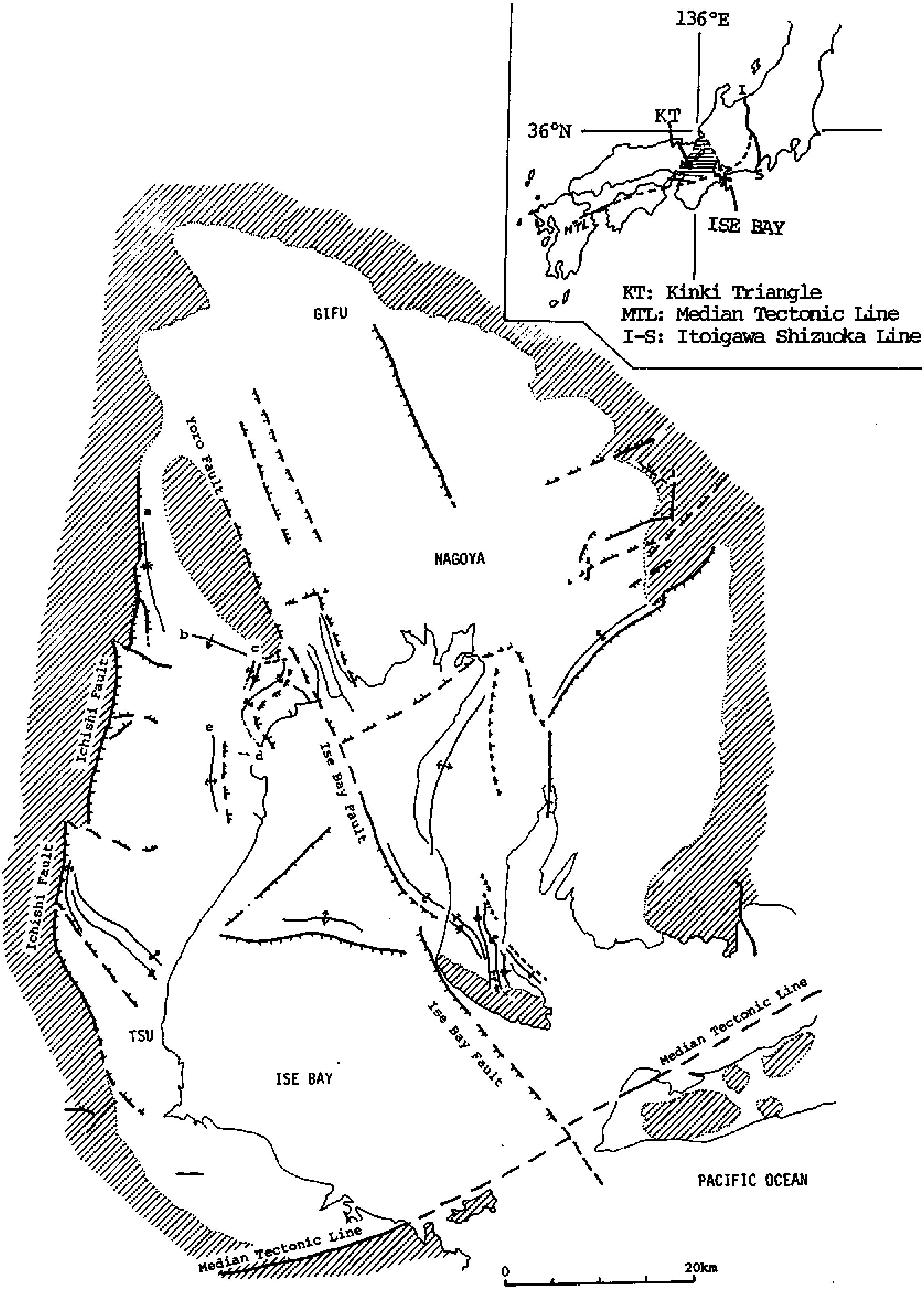


Fig. 30. Geologic structure around Ise Bay (after Makinouchi, 1979, partly modified). a: Shinodate Syncline b: Ichinohara Flexure c: Igai Anticline d: Kuwana Anticline e: Yokkaichi Flexure

surveyed area is included in the "Age subbasin" in this sense, and it is characteristic that the Tokai Group forms a basin structure there. In this area, tectonic lines represented by fault, fold and flexure are recognized, which are coupled with three different trends such as Setouchi, Suzuka and Yoro trends.

Generally, in the west of the surveyed area the Tokai Group is contact by the Ichishi Fault with the Paleozoic rocks and Cretaceous granite of the Suzuka Mountains. In the east, that group rests unconformably on the Mesozoic and Paleozoic of the Yoro Mountains. In the western foothill area of the Yoro Mountains, N 20°W is a general strike trend of the Tokai Group in the northern part, while it changes to about N 40°W in the southern part. Dipping gently to the west at 20-30 degrees, the Tokai Group exposes its upper part to southwest. On the other hand, in the eastern foothill area of the Suzuka Mountains, the strike trend of the Tokai Group is nearly N-S, dipping to east at 60-40 degrees (Fig. 31).

The Yoro-Ise Bay Fault, Ichishi Fault and Kuwana Anticline are recognized as the first grade tectonic structure. Among them, the first represents southern half of great fault zone which demarcates the Kinki Block from the Chubu Block. The Yoro Fault runs with the NNW-SSE trend at eastern foothill area of the Yoro Mountains. The western side of this fault (Yoro Mountains) was elevated relatively, and amount of its total vertical displacement might exceed 1,500 m. The Ise Bay Fault in Ise Bay (Kuwahara, 1969; Chujo and Suda, 1971)

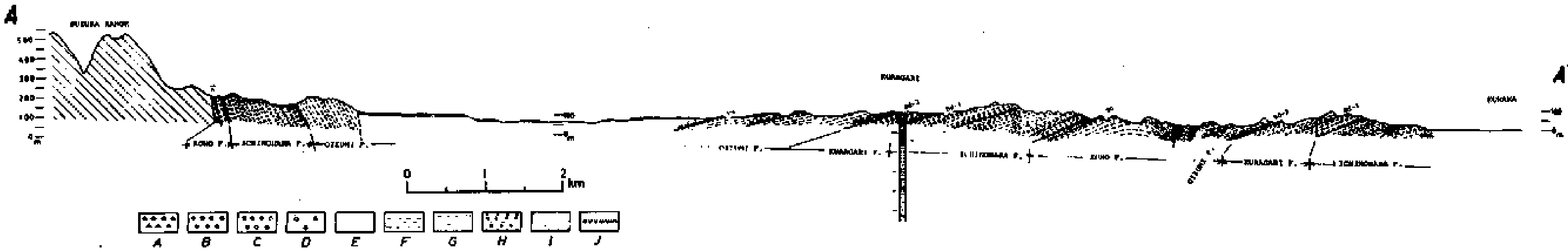


Fig. 31. Geologic profile of the Tokai Group in Hokuse area (E-W section) (profiling line: see Fig. 3).

has been recognized only by seismic profilling and gravitational survey. Its trend is NNW-SSE direction and it is recognized that eastern part of this fault was elevated relatively.

The west end of the Agė Subbasin is limited by the Ichishi Fault (Takimoto, 1935). This fault runs from Tara to Matsusaka along the eastern foothill area of the Suzuka Mountains. It extends about 60 km in N-S direction, but, in precisely this fault is composed of small faults in echelon. Generally, this fault runs between the Tokai Group and basement rocks including Miocene strata, and especially around Tsu and Seki area, the Tokai Group is clearly contact with the Miocene deposits by this fault. In this case, it is sure that this fault is related to an upheaval of western Suzuka Mountains, but the dip of fault plane is almost in vertical. The Tokai Group which is distributed at the eastern side of this fault dips steeply at about 50-80°E, and makes a zone of steep dipping strata of about 1 km wide.

The Kuwana Anticline is an asymmetric folding, which runs from Shimonoshiro, Tado-cho to the west of Yokkaichi City along the coast of Ise Bay. At the Kuwana Hills, west of Kuwana City, it has N-S trend, while it turns to NNE-SSW at the Kaki and Oyachi Hills of the south. The strata of the western wing incline about 10 degrees to west, while those of the eastern wing steeply dip about 60 degrees to east.

The another steep dipping zone of the Tokai Group (Ichinohara

Flexure Zone" by the author) is traceable from Ageki to Kono in the foothills of the Yoro Mountains, and is with E-W trend. In this zone, the strata incline steeply to southward, 40-60 degrees in the south of Ichinohara and about 25 degrees at the west of Ageki. In the southwest of Chikarao, an asymmetric anticline is observed, which is called as the Igai anticline (Matsui, 1943). In the west wing of this anticline, the strata of the Tokai Group dip toward southeast at 10-20 degrees. In the east wing, the strata dip at 80-90 degrees eastwardly (Fig. 32).

In the Tara area, the Tokai Group of the narrow belt between the Suzuka and Yoro Mountains, forms a conspicuous synclinal structure. This syncline was called "Shinodate Syncline" by Miyamura et al. (1976).

III. PALEOGEOGRAPHY AND TECTONISM OF SEDIMENTARY BASIN OF LAKE TOKAI

In the preceding chapter, the stratigraphy, geologic structure and chronology of the Tokai Group in the central and northern areas on the west coast of Ise Bay (Sekigahara to Yokkaichi areas) were described. In this chapter, at first, correlation and classification of the Tokai Group will be proposed, and in the second, the paleogeography on the basis of stratigraphy, choronology and sedimentology of Lake Tokai will be discussed. Lastly, tectonism since Pliocene

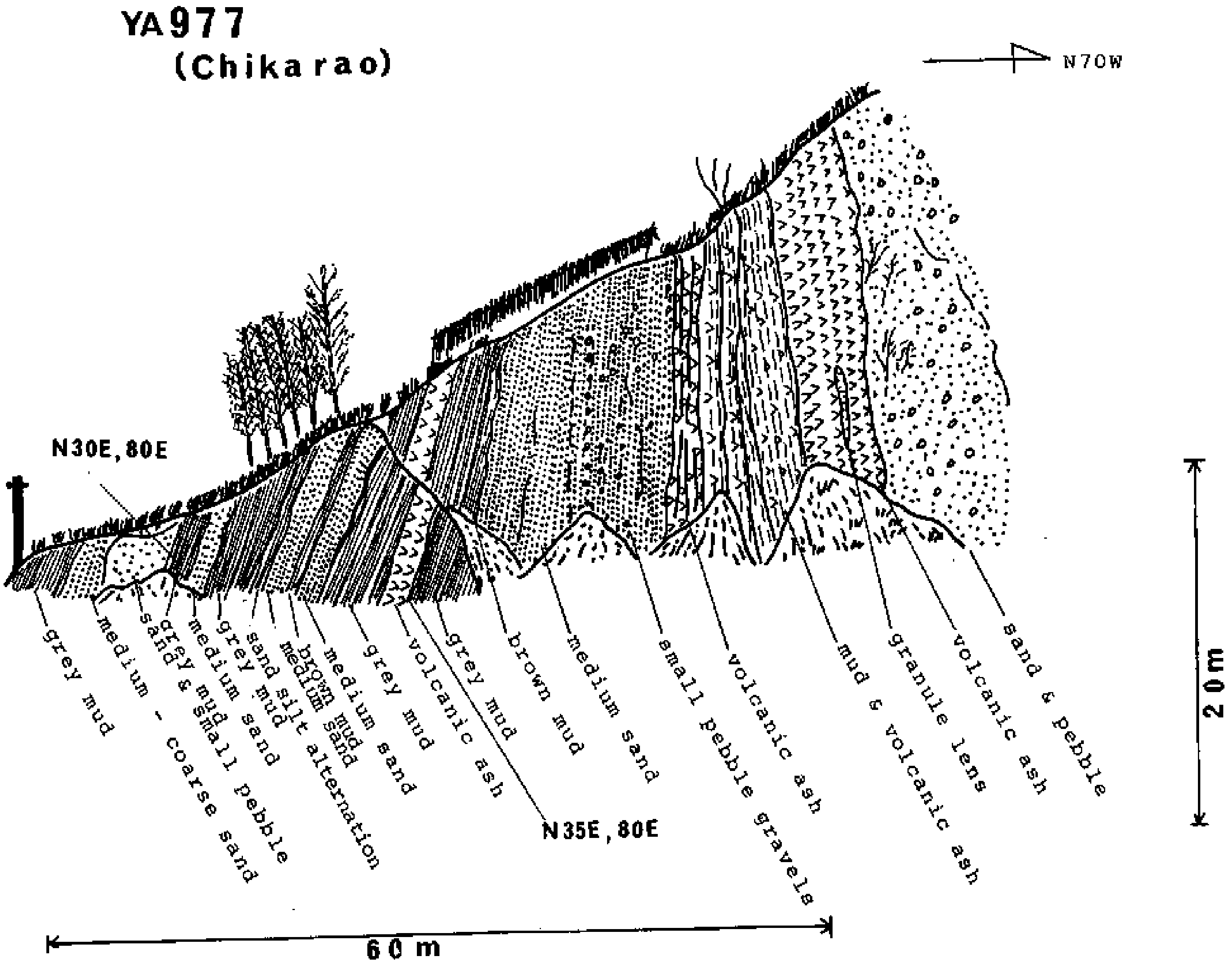


Fig. 32. Sketch of the east wing of the Igai anticline.

around Ise Bay will be considered.

A. CORRELATION AND SUBDIVISION OF THE TOKAI GROUP

As mentioned before, the Tokai Group is distributed mainly around Ise Bay.

The Tokai Group around Nagoya City is called the Seto Group (Makiyama, 1950), and Matsuzawa et al. (1960) subdivided it into two formations, the Seto porcelain clay deposits and the Yadagawa Formation. Mori (1971a) studied tephrostratigraphically the Yadagawa Formation, and subdivided it into three members. They are Mizuno (gravels, or sands and gravels dominant), Takahari (irregular alternating beds of lignite, clay, and gravel), and Idaka (alternating beds of gravel, sand and silt) members in ascending order.

The Tokai Group in the Chita Peninsula is called the Tokoname Group (Ose, 1929), and was studied tephrostratigraphically by Itoigawa (1971), and Makinouchi (1975a). Makinouchi (1975a) divided those sediments into three formations: Toyooka (gravel Kouwa (irregular alternating beds of sand and mud), and Futto Formations (irregular alternating beds of sand and mud) in ascending order.

Recently, the Tokai Group in the southern part of the west coast of Ise Bay (Nanse) was surveyed by Miyamura et al. (1981) and Wada (1982). Miyamura et al. (1981) subdivided those sediments into the Saigyodani Gravel, Kusuhara coal bearing-, Kameyama and Sakuramura Formations in ascending order.

Previously, a correlation scheme among the sediments of the Tokai Group was proposed by Ishida and Yokoyama (1969). In this study, they correlated the Tokai Group with the Kobiwako and Osaka Groups, on the basis of the common characteristic volcanic ash layers distributed throughout those groups. They regarded the volcanic ash layers which contain abundant pumice grains like as Shinden volcanic ash layer of the Osaka Group, Mushono volcanic ash layer of the Kobiwako Group, Pumice, Akogi and Ohtani volcanic ash layers of the Tokai Group as an identical volcanic ash layer and then called them collectively "Pumice volcanic ash layer". Mori(1971a), however, proposed another scheme. He correlated the Togo volcanic ash layer of the Yadagawa Formation in Nagoya (including many pumice grains), refering to the thickness and mineral composition, to the Ohta volcanic ash layer in the northern area of the Chita Peninsula (Itoigawa, 1971) and the Akogi volcanic ash layer of the Nanse area (Itoigawa and Mori, 1971). Further, he insisted that the Karegawa volcanic ash layer of the Hokuse area (Mori, 1971b) (Pumice volcanic ash layer) is situated stratigraphically higher than the Akogi volcanic ash layer. Makinouchi(1975) also correlated the Ohtani volcanic ash layer in the southern part of the Chita Peninsula to each of the Togo, Ohta and Akogi volcanic ash layers. By activation analysis of pumice grains, it becomes clear that the Pumice volcanic ash layer of the Hokuse area is substantialy different from the Akogi volcanic ash layer, and that the Ohtani volcanic ash layer is possibly correlated with the Akogi volcanic ash layer (Ikeda et al., 1977; Yokoyama et al., 1978). Consequently, based on those results, the correlation of the Tokai Group on both sides of the Ise Bay, (Chita and Nanse areas) comes to be established. Moreover, the Bando-1 volcanic ash layer in the northern Ise area can be correlated with the Onbegawa volcanic ash layer in the southern Ise area, and thus, the stratigraphical relataionship between the Hokuse and Nanse areas is also clarified as shown in Fig. 33.

Then, apart from those tephrostratigraphical studies, many data of paleomagnetism and fission track ages have been gradually accumulated. Otofuji et al.(1975) carried out NRM measurements for the Tokai Group in the Chita Peninsula and reported the presence of reversed polarity of the sequence between the Koba and Sakai volcanic ash horizons of the upper half, and normal polarity between the Kaminoma and Kofu volcanic ash horizons of the lower half. The fission track ages of volcanic ash layers in the Tokai Group in the Chita Peninsula were measured by Makinouchi et al.(1982). They are as follows: Ohtani volcanic ash layer; 4.3 m.y., Kosugaya volcanic ash layer; 4.2 m.y., Kaminoma volcanic ash layer; 5.3 m.y. In addition, taking the fission track age of the Kamishiraki volcanic ash layer (3.6 ± 0.2 m.y.) into consideration, the Tokai Group of the Chita Peninsula is correlated with the deposits of the Gilbert Reversed Epoch to the Epoch 5. Because, as stated precedingly, the Akogi volcanic ash layer of the Nanse area corresponds to the Ohtani volcanic ash layer of the Chita Peninsula.

Summarized above, the correlation chart of the Tokai Group is shown in Fig. 33.

The basal horizon of the Tokai Group is different from place to place. At the Chita Peninsula, it is about 350 m lower than the Ohtani volcanic ash layer (Makinouchi, 1975a), at Tsu area, it is about 400 m lower than the Akogi volcanic ash layer (Itoigawa and Mori, 1971), at Kameyama area, it is about 350 m lower than the Akogi volcanic ash layer (Miyamura et al., 1981), and in Nagoya, it is about 100 m lower than the Togo volcanic ash layer (Mori, 1971a). It is evident that the basal horizon is relatively higher in the northern area than in the southern area. It follows that the sedimentary basin of Lake Tokai in the Chita Peninsula initiated about 6.0 m.y. B.P. In connection with this, in the Nagoya and Chita areas, as the upper limit of the Tokai Group is defined at the horizon of about 250 m higher than the Ohtani (Togo) volcanic ash layer, the deposition terminated at 3-3.5 m.y. B.P.

On the other hand, the deposition of the Tokai Group in the Hokuse area is initiated about 3.0 m.y.B.P. This horizon is correlated with the middle Kameyama

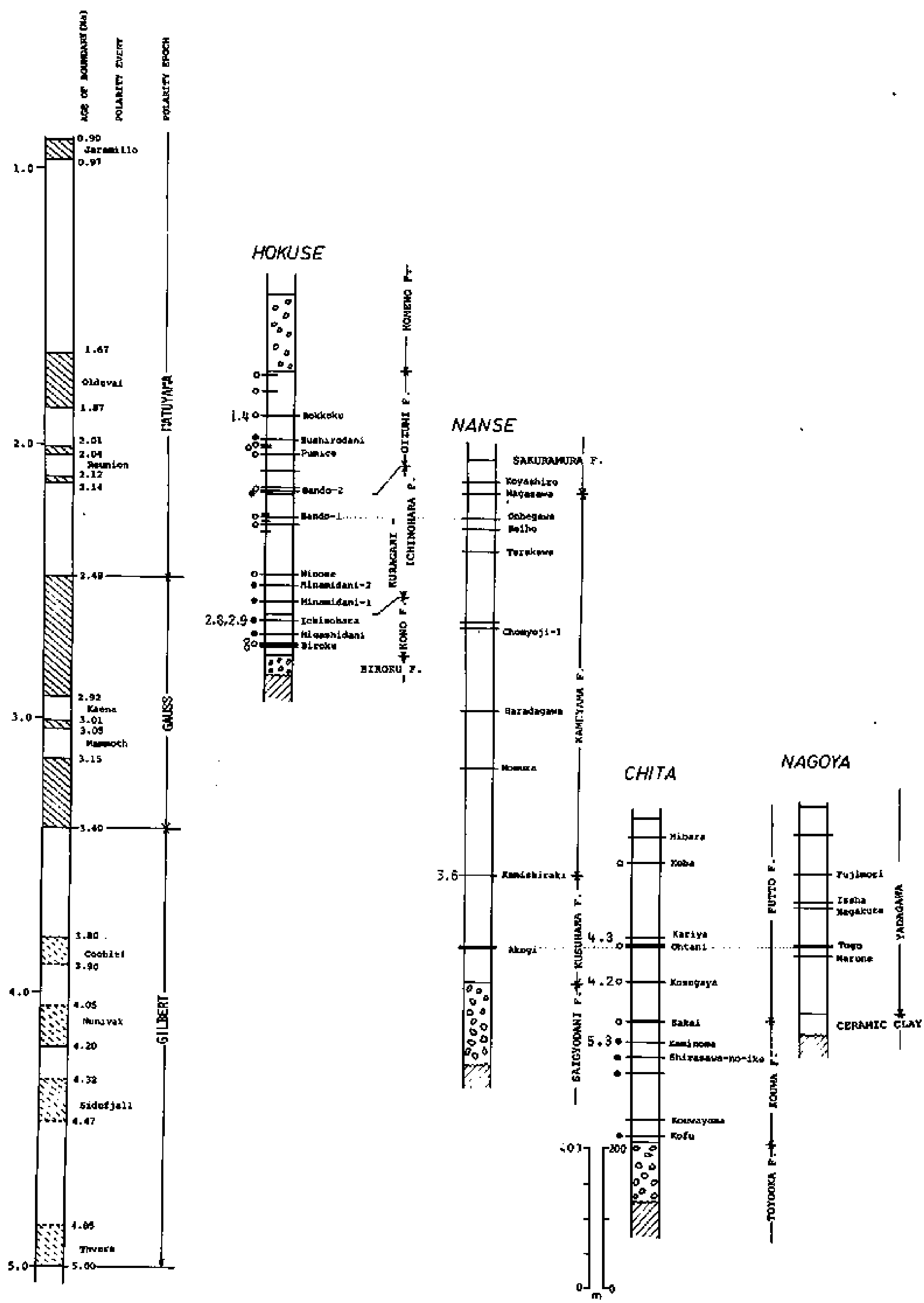


Fig. 33. Correlation chart of the Tokai Group among Hokuse, Nanse, Chita and Nagoya.
Hokuse: Takemura (1978), Nanse: Miyamura et al.(1981), Chita: Makinouchi (1975), Nagoya: Mori (1971).

Formation in the Kameyama area. Furthermore, the depositional age of the uppermost Tokai Group in the Hokuse area is about 1.2 m.y. B.P.

To conclude, the sedimentary basin of Lake Tokai was first formed at the area of the Chita Peninsula in the southeast and Nanse of the west, and successively expanded to the northern area. Consequently, the center of the basin migrated to the Hokuse area at the time of 3.0 m.y. B.P. Accordingly, it is convenient to subdivide the geohistory of the sedimentary basin into two stages; Stage I and Stage II, with the boundary at about 3.0 m.y. B.P. (Table 5).

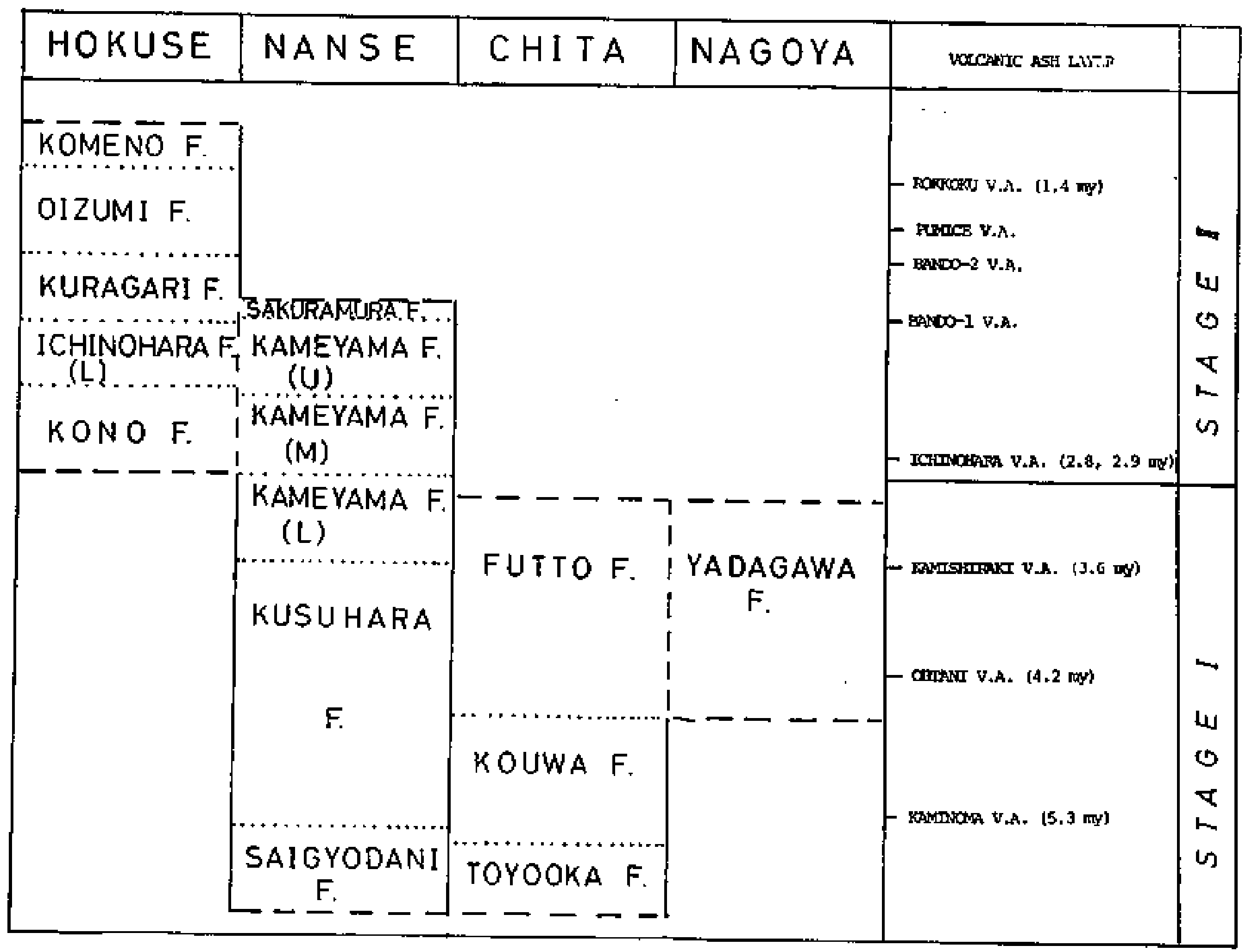
B. SEDIMENTARY ENVIRONMENTS OF THE TOKAI GROUP

As mentioned before, the geohistory of the sedimentary basin of Lake Tokai can be divided into two stages, Stage I and Stage II. In this section, the sedimentological discussion on those deposits (distribution, lithology, composition of gravels and paleocurrent) are intended.

a. Stage I.

The sediments of Stage I are widely distributed in the southern Ise area, in the Chita Peninsula and in the area around Nagoya City. They are represented by the Saigyodani gravel Formation, Kusuhara coal-bearing Formation and the lower Kameyama Formation (alternating beds of sand and mud) of the

Table 5. Subdivision of the sedimentary basin of Lake Tokai.



Nanse area; the Toyooka Formation (gravels), the Kouwa Formation (alternating beds of sand and mud with lignites) and the Futto Formation (alternating beds of sand and mud) of the Chita Peninsula, and the Mizuno Member (gravels, or sands and gravels), the Takahari Member (irregular alternating beds of lignite, clay, and gravel) and the Idaka Member (alternating beds of gravel, sand and silt) of the Nagoya area.

As the lowermost horizon of this stage, the Saigyodani and Toyooka Formations are typically enumarated. The Saigyodani gravel Formation of southwest coast of Ise Bay is composed mainly of thick gravel bed with pebble to cobble gravels. The gravel bed is composed mainly of chert, shale, sandstone and hornfels gravels along with the gravels of "quartz porphyry" and granite. From the compositional analysis, two types of gravel facies are recognized. One is the gravels containing granite and sandstone derived from the neighbouring Miocene Suzuka Group. The other is characterized in containing mainly gravels of "quartz porphyry" transported from distant area. This "quartz porphyry" is composed of ryolitic welded tuff. The sedimentary environment of the Saigyodani Formation was the mixture of alluvial fan and fluvial environments which includes drainage area of rhyolitic welded tuff.

The Toyooka Formation of the Chita Peninsula is also composed of thick gravels, the fluvial origin. Gravel bed contains chert, Paleozoic sandstone, sandstone of the Miocene Morozaki Group and crystalline schist. The size of gravel decreases westward and, at the west coast of the Chita Peninsula, this formation becomes to be composed of sands and gravels, or medium to coarse sands with gravels. Lateral variation of gravel composition is not detected, but, cross laminations which indicate paleocurrent from east to west are developed within the sediments(Makinouchi, 1975a). Conclusively, it is assumed that the Toyooka Formation was deposited under fluvial environment in which gravels were supplied from east includnig drainage area of crystalline schist.

After the deposition of that gravels, the Kouwa Formation and the Kusuhara coal-bearing Formation were deposited in the Chita Peninsula and the Nanse area respectively. The Kouwa Formation is composed of irregular alternating beds of sand and mud with lignite beds. At the east coast of the Peninsula sand layers are dominant, while at the west coast mud layers are dominant. Paleocurrent directions indicate that the sediments were supplied from east. Lignite beds are developed in those sediments. These evidences show that the Kouwa Formation was deposited under shallow lacustrine conditions. The Kusuhara coal-bearing Formation consists also of alternating beds of mud and sand, accompanied with large amount of lignite beds. In the area around Kameyama, it contains gravel beds, and is thinning down northward (Fig. 34). From those sediments, freshwater

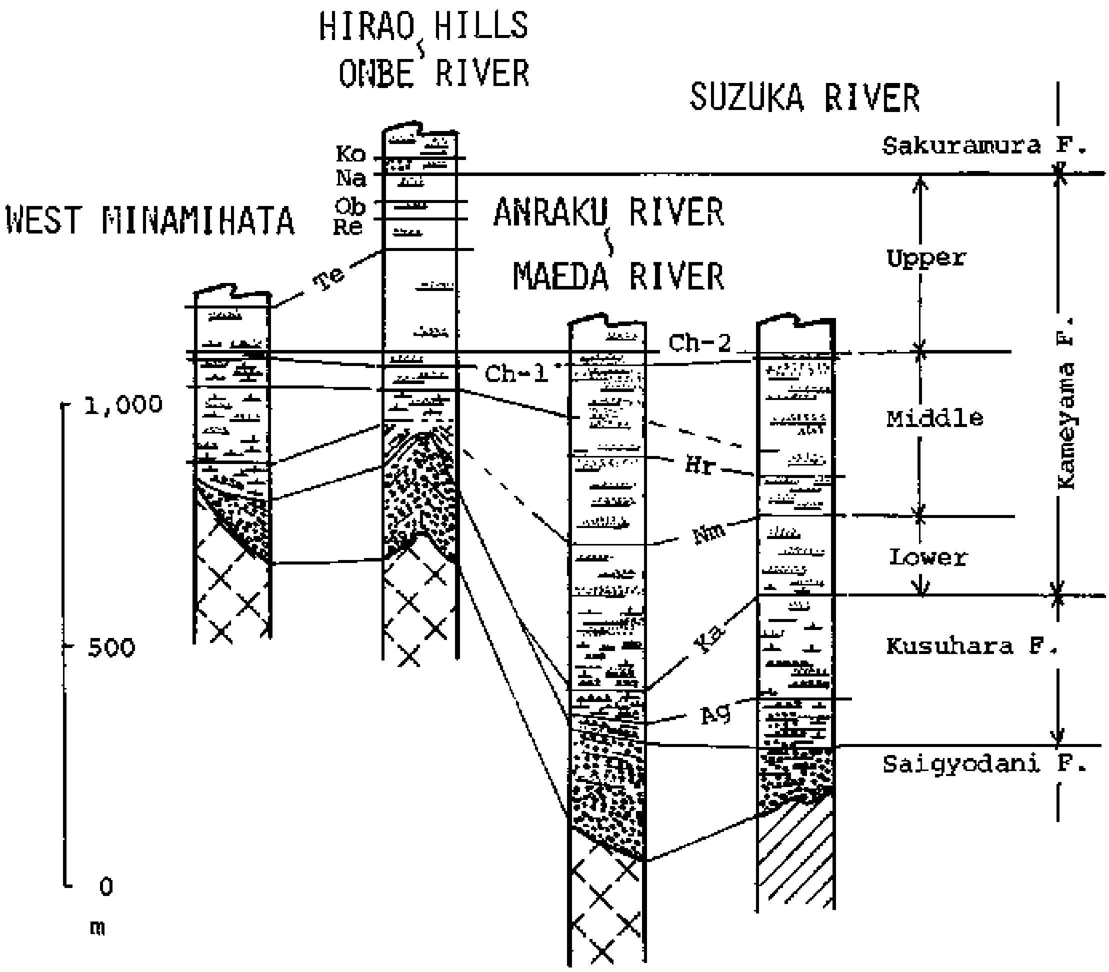


Fig. 34. Columnar sections of the Tokai Group in Kameyama area (after Miyamura et al., 1981).

molluscs occur, and lignite beds are developed in them. It should be noted that sediments in Kameyama area are coarser than that in Tsu area. Therefore, the Kusuhara coal-bearing Formation deposited under shallow lacustrine environment, but occasionally the area around Kameyama turned to alluvial plain.

Subsequently, the Futto Formation was deposited in the Chita Peninsula, and also the upper part of the Kusuhara Formation war deposited in the Nanse area simultaneously. Furthermore, northward expansion of the sedimentary basin brought about the deposition of the Yadagawa Formation in the Nagoya area. The Futto Formation is composed of alternating beds of sand and mud containing lignite beds with coarse materials at its basal part. The Futto Formation was deposited under shallow lacustrine environment. Paleocurrent direction deduced from cross laminations is from north to south. The Yadagawa Formation contains large amount of gravels, suggesting them to be alluvial fan or plain. In the Nanse area, after the deposition of the Kusuhara coal-bearing Formation, the lower part of the Kameyama Formation, which is composed of alternating beds of sand and mud, was deposited under lacustrine environment.

b. Stage II.

The sedimentary suits assigned to Stage II are distributed exclusively on the west coast of Ise Bay, and mainly in the Hokuse area. Therefore, at first, lithology and sedimentology of those sediments in the Hokuse area will be mentioned, and in the second, those around Kameyama area will be stated.

Biroku Formation is locally distributed in the foothills of the Yoro and Suzuka Mountains. It is composed of pebble to cobble gravels with small amount of boulder gravels, and is composed almost entirely of sandstone derived from the basement of the Mesozoic and Paleozoic rocks. They are alluvial fan deposits.

Kono Formation is distributed from Inabe to Kuwana area. The lower part of it is composed of alternating beds of sand and mud with large amount of lignite beds (Table 6), suggesting that this formation was deposited under shallow lacustrine environments. In the sediments, the amount of sand layer increases to the upper, while that of lignite decreases vice versa.

Ichinohara Formation has two sedimentary facies. One is characteristically has alternating beds of gravels and mud (Inabe facies). The other (Kuwana facies) is characterized by the presence of alternating beds of sand and mud. The former is the sediments deposited under alluvial plain to lacustrine environments. The amount of gravel in the sediments decreases gradually from northwest to southeast (Fig. 35, Table 7). The thickness of each sedimentary cycle of gravel and mud decreases southeastward, laterally, and it decreases upward vertically. The gravels are composed of chert, sandstone and

Table 6. Lithologic proportions of sediments of the Kono Formation.

Locality	area	gravels	sand & gravels	sand	alt.	mud
Akechi R.	A	-	-	15.5	-	84.6
Ichinohara	A	-	-	2.5	42.6	55.0
E. Ichinohara	A	-	-	12.5	24.1	63.4
Higashidani	A	-	-	12.1	30.9	57.0
Kono Minamidani	A	-	-	19.0	12.4	68.6
Kono Minamidani	A	-	-	18.3	29.4	70.6
Kono Minamidani	A	-	-	32.4	3.4	64.2
Tashida R.	C	-	-	15.8	10.5	73.7

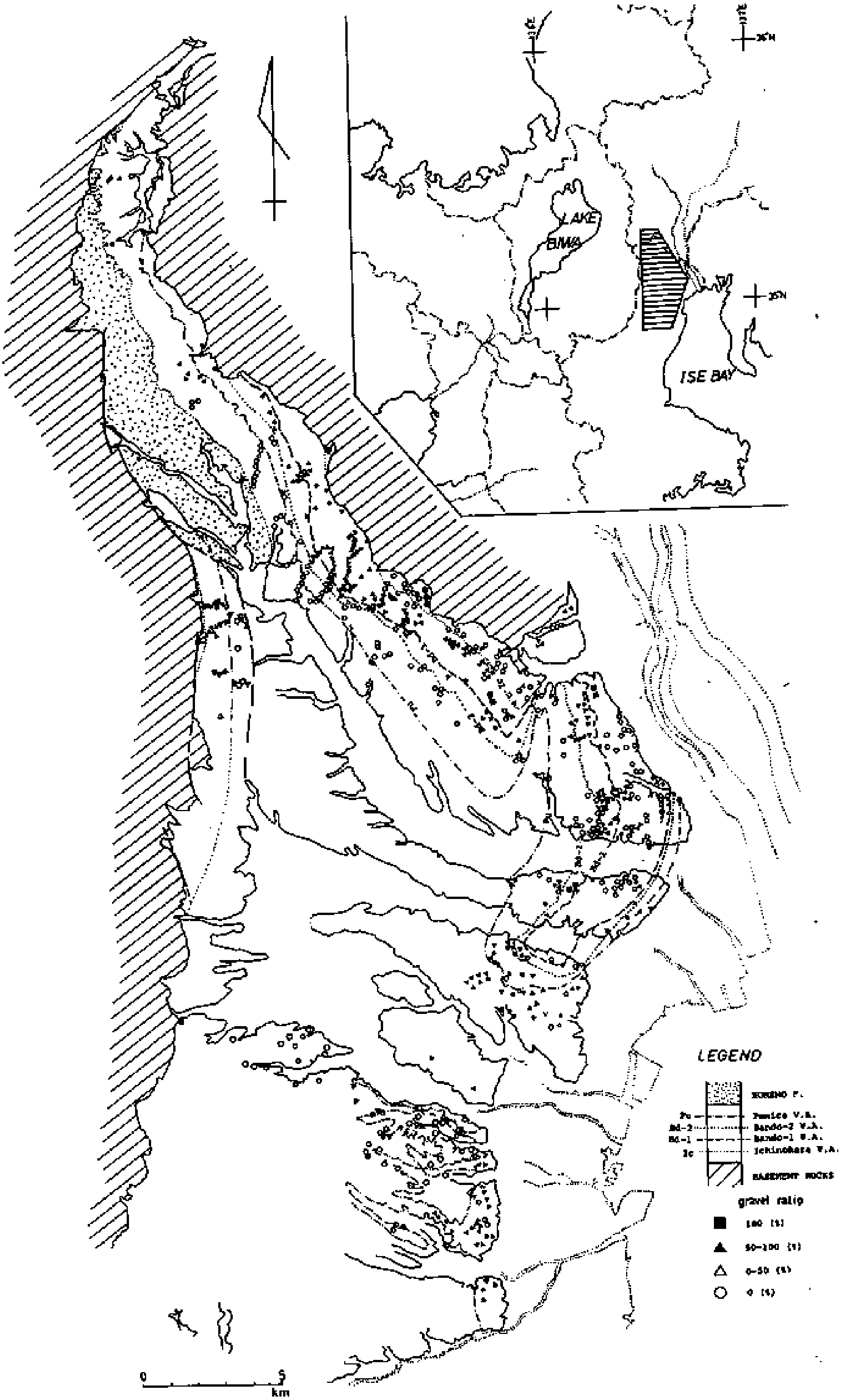


Fig. 35. Gravel ratio in sediments of the Tokai Group at each outcrop.

Table 7. Lithologic proportions of sediments of the Ichinohara Formation.

Locality	area	gravels	sand & gravels	sand	alt.	mud
Tashida R.	C	66.5	4.3	3.8	4.7	20.6
Sejihara	B	35.1	17.9	15.5	2.5	29.0
Nishikoyamadani	A	57.7	-	5.1	4.6	32.6
Higashikoyamadani	A	53.7	-	8.9	4.4	33.0
Yamada R.	A	45.5	7.9	4.5	14.0	28.1
Rengedani R.	A	30.5	2.4	7.3	6.7	53.1
Akechi R.	A	37.1	8.8	5.9	8.3	40.0
Togami R.	A	24.2	13.1	17.7	17.7	27.4
Kono Minamidani	A	40.0	8.1	11.6	5.6	29.2
Kono Minamidani	A	27.1	17.2	22.9	15.3	17.2
Kono Minamidani	A	16.6	-	22.6	-	60.9
Okushinden	D	-	4.5	27.7	-	67.8
Nukata	D	-	12.0	28.8	21.7	37.5
Kaki	E	-	5.1	33.3	5.2	56.5

shale gravels originated from the Mesozoic and Paleozoic rocks (Fig. 36 and Table 8). The Kuwana facies of the Ichinohara Formation, alternating beds of sand and mud is the sediments under lacustrine environments.

Kuragari Formation is distributed in the area from Kuwana to Hirako, and is composed of pebble to cobble size and subround to subangular gravels with sandy matrix. Cross laminations are developed in the sandy part, and small amounts of mud layers are intercalated. Therefore, the sediments were deposited under alluvial plain environments. The amount of gravels in the sediments is the highest in the Kuwana area, and decreases both southward and westward (Table 9). The gravels consist of chert, sandstone and "quartz porphyry", the last one generally represented by rhyolitic welded tuff of Mesozoic volcanics, which are distributed at an eastern area of the sedimentary basin (Nohi area) (Fig. 37). The cross laminations suggest the paleocurrent direction from NE to SW (Fig. 38, Table 10 and 11).

As for the Oizumi Formation, four lithofacies are recognized. They are alternating beds of gravel and mud facies (Tara facies), alternating beds of sand and mud facies, sandy alternating beds of sand and mud facies, and sands and gravels. The first one is distributed around the Tara area, the amount of gravels in the sediments decreases

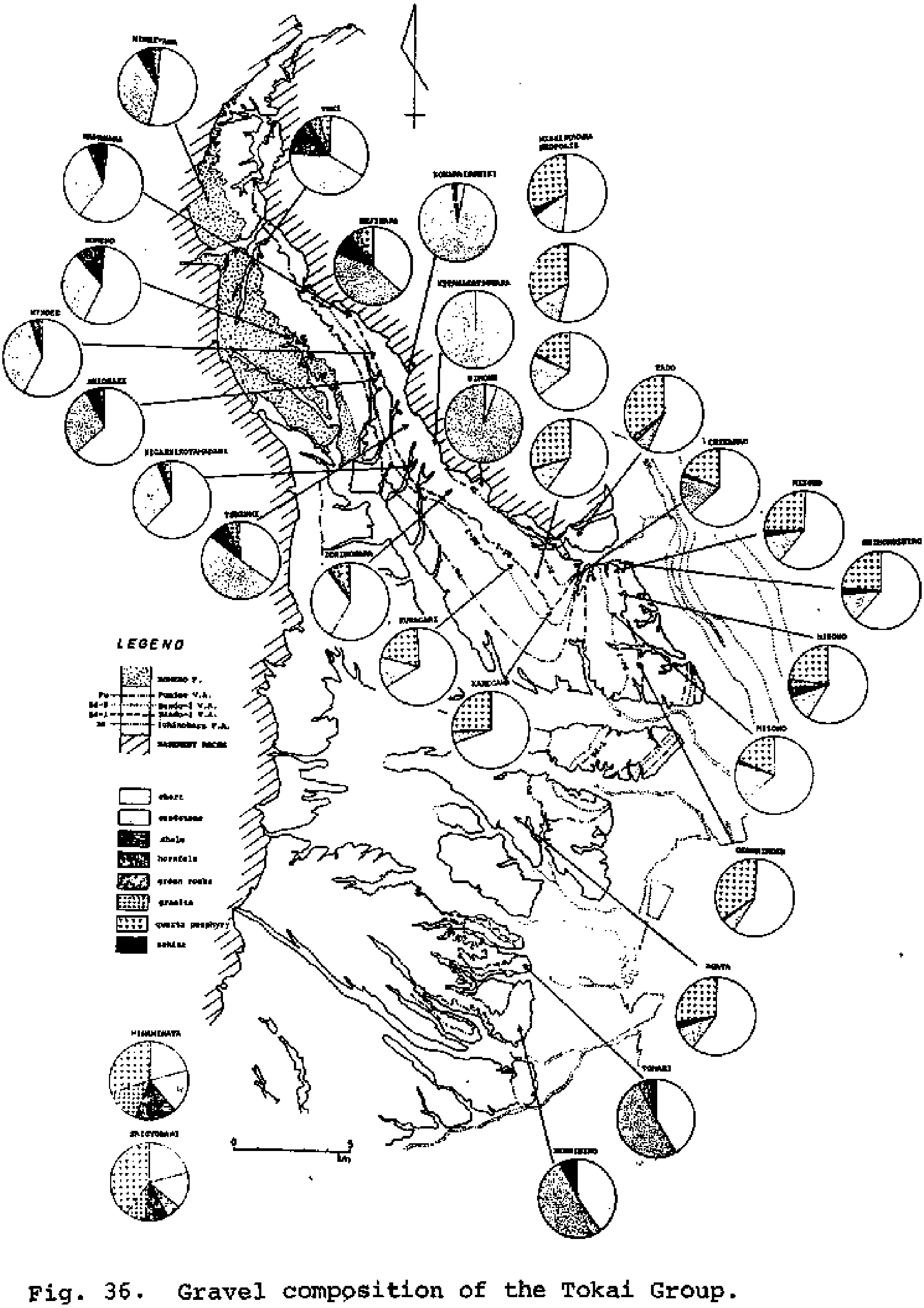


Fig. 36. Gravel composition of the Tokai Group.

Table 8. Composition of gravels.

Locality	Area	Horizon	Ch	SS	Sh	Ho	Gre.	Gr	QP	Sch
Saigyodani	(G)	Saigyodani F.	21.0	15.0	6.0	9.5	0.0	8.0	40.5	0.0
Minamihata	(G)	Saigyodani F.	20.5	18.0	6.0	10.5	0.0	14.0	31.5	31.0
Biroku	(A)	Biroku F.	5.0	95.0	-	-	-	-	-	-
Koharaisshiki	(A)		3.0	95.0	-	2.0	-	-	-	-
Kitanakatsuhara	(A)		-	100	-	-	-	-	-	-
Sejihara	(B)	Ichinohara F.	37.0	43.5	6.0	2.0	1.0	3.5	7.0	-
Kawahara	(A)		58.5	33.5	4.0	1.0	1.0	0.5	1.5	-
Shiosaki	(A)		63.5	29.0	4.5	-	1.0	-	2.0	-
Ninose	(A)		57.5	37.0	1.0	-	2.5	-	2.0	
Higashikoyamadani	(A)		62.8	32.0	1.7	-	0.6	0.6	2.3	-
Tsuzumi	(A)		34.9	50.7	4.9	-	3.4	4.8	1.4	-
Ichinohara	(A)		58.8	31.4	1.1	-	-	2.7	6.0	-
Kuragari	(A)	Kuragari F.	66.6	12.9	-	-	-	-	20.5	-
Nishikuwana n.p.	(A)		52.5	13.5	1.5	1.0	-	-	31.5	-
Nishikuwana n.p.	(A)		64.7	16.7	0.5	-	-	0.5	17.6	-
Nishikuwana n.p.	(A)		53.6	12.9	-	-	-	-	33.5	-
Nishikuwana n.p.	(A)		59.2	9.9	-	-	-	0.5	30.4	-
Karegawa	(A)		69.5	4.4	-	-	-	0.5	25.6	-
Chikarao	(A)		63.3	16.1	-	-	-	1.1	19.5	-
Tado	(D)		56.5	6.0	0.5	-	-	1.5	35.5	-
Mizono	(D)		58.7	10.9	3.6	-	-	4.0	22.7	-
Mizono	(D)		60.1	11.7	2.5	-	-	-	25.7	-
Mizono	(D)		63.5	16.3	0.8	-	-	0.4	19.0	-
Shimonoshiro	(D)		61.3	11.7	2.4	-	0.4	-	24.2	-
Okushinden	(D)		58.0	5.5	-	0.5	-	-	36.0	-
Toki	(B)	Oizumi F.	33.0	42.0	8.5	2.5	4.0	4.5	5.5	-
Agata	(E)		59.5	9.8	2.6	-	-	-	28.1	-
Tomari	(F)		41.0	51.0	-	-	-	3.5	1.5	3.0
Nishihino	(F)		40.0	52.0	-	-	-	-	-	8.0
Nishiyama	(B)	Komeno F.	52.0	38.0	3.0	3.0	-	4.0	-	-
Komeno	(B)		56.0	32.0	7.5	2.5	-	1.0	1.0	-

Table 9. Lithologic proportions of sediments of the Kuragari Formation.

Locality	area	gravels	sand & gravel	sand	alt.	mud
Kuragari	A	60.2	12.0	12.8	-	14.9
Mizono	D	59.3	5.2	14.5	-	21.0
Okushinden	D	64.0	7.9	11.1	-	16.9
Nukata	D	66.2	10.6	6.6	-	16.6
Kaki (W)	E	50.2	20.8	4.3	9.9	14.9
Kaki (E)	E	36.0	19.4	18.2	-	26.3
Oyachi	E	27.0	18.0	8.7	3.5	42.8

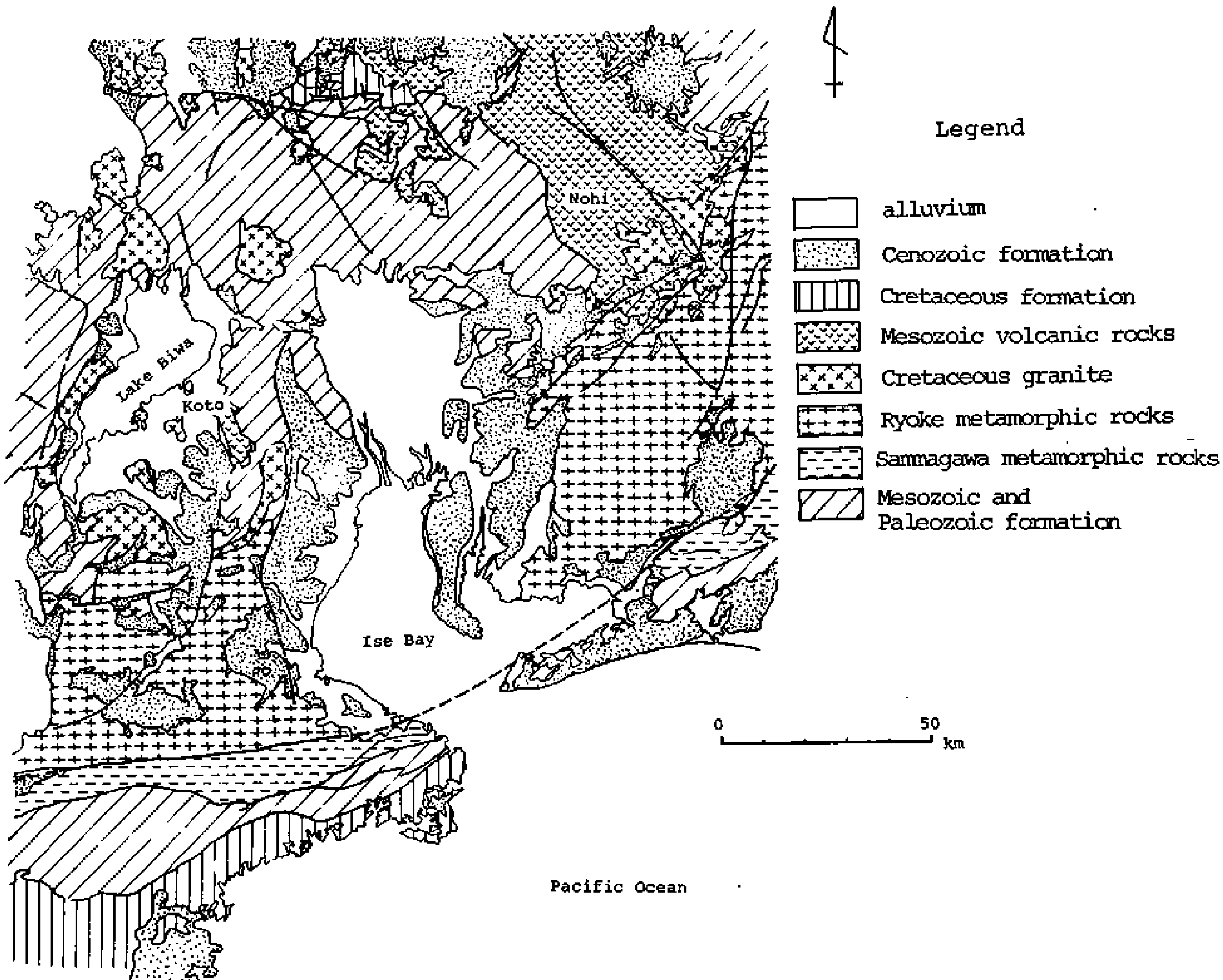


Fig. 37. Geologic system around Ise Bay.

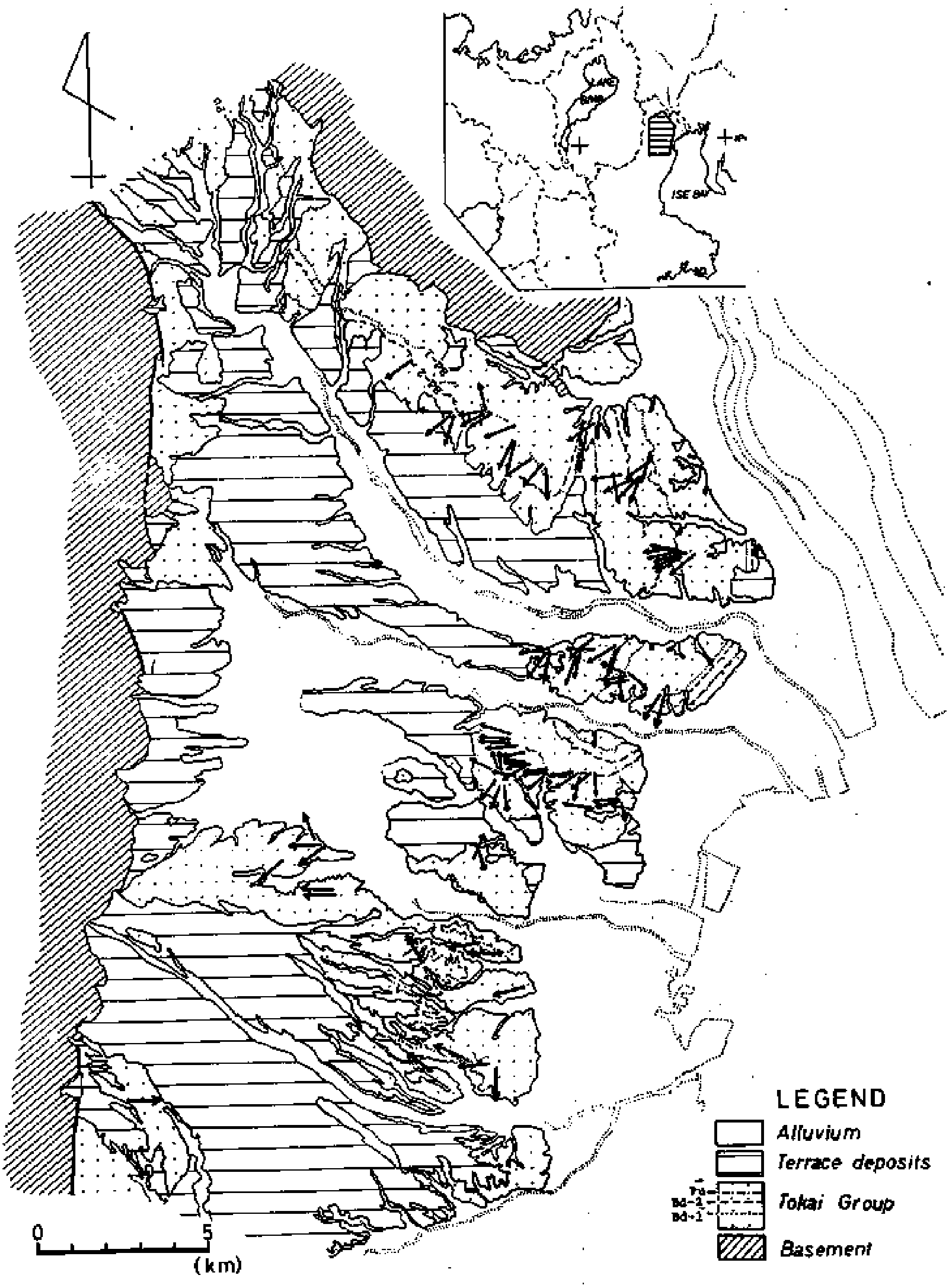


Fig. 38. Paleocurrent directions of the Tokai Group on the west coast of Ise Bay.

Table 10. Paleocurrent direction deduced from cross laminations in Inabe and Kuwana area.

Locality	Horizon	Mean direction of paleocurrent	Consistency ration	Number	Average dip
Kuragari (N)	Kuragari F.	98	99.9	3	23.3
Kuragari (N)		186	99.8	5	24.6
Kuragari (N)		205	99.7	4	37.3
Kuragari (N)		210	99.7	10	25.1
Kuragari (E)		213	99.5	10	31.5
Kuragari (E)		241	99.1	6	32.0
Kuragari (E)		200	99.7	3	23.7
Kuragari (E)		253	99.5	8	33.9
Karegawa (W)		271	99.8	5	28.2
Karegawa (W)		228	99.9	2	16.5
Karegawa (W)		255		1	18.0
Mizono (S)		258	99.6	5	19.6
Mizono (S)		213	99.6	5	28.1
Mizono (S)		220	99.6	11	35.8
Mizono (S)		199	99.5	8	31.3
Mizono (S)		180	99.7	11	36.5
Mizono (S)		243	99.6	10	37.0
Okushinden (S)		206	98.9	5	31.2
Okushinden (S)		168	99.9	3	32.4
Okushinden (S)		208	99.9	5	30.8
Okushinden (S)		180	99.7	6	36.9
Okushinden (S)		185	99.8	10	36.5
Okushinden (S)		206	99.8	10	35.7
Okushinden (S)		212	99.8	10	39.0
Ichinohara (S)	Oizumi F.	212	98.9	9	34.7
Kuragari (N)		183	98.5	7	29.4
Kuragari (N)		248	99.3	6	31.5
Kuragari (N)		218	99.6	5	27.6
Chikarao (E)		212	98.4	9	28.2
Mizono (S)		280	99.8	5	33.3

Paleocurrent direction, that is, vector means are represented by anticlockwise angle from east direction.

Table 11. Paleocurrent direction deduced from cross laminations in the Kaki area.

Locality	Horizon	Mean direction of paleocurrent	Consitency ratio	Number	Average dip
Akao (S)	Kuragari F.	246	99.1	8	24.0
Akao (S)		204	99.0	9	25.3
Isaka (N)		323	99.7	3	26.8
Isaka (N)		185	99.3	10	25.9
Isaka (N)		152	99.9	5	26.8
Isaka (N)		181	99.2	7	23.9
Isaka (N)		272	99.7	3	21.4
Yamamura		229	99.6	8	38.7
Yamamura		250	99.6	5	37.6
Shimada	Oizumi F.	216	99.8	5	39.0
Shimada		174	99.8	10	28.9
Shinden (S)		256	99.5	5	27.8
Shinden (S)		186	99.6	5	39.0
Shinden (S)		255	99.2	6	22.3
Shinden (S)		232	99.9	2	20.5
Isaka dam (N)		258	99.8	5	26.7
Isaka dam (N)		251	99.6	7	21.8

Paleocurrent direction, that is, vector means are represented by anticlockwise angle from east direction.

southward (Table 12). Gravels are mainly composed of chert, sandstone, and shale from the basements of the Mesozoic and Paleozoic rocks (Fig. 36 and Table 8). Therefore, the sediments of this facies were deposited under alluvial plain environments with some lacustrine episodes. The second facies of alternating beds of sand and mud is distributed from Inabe to Kuwana area. The occurrence of fossil diatoms and molluscs suggest that this facies was deposited under stable lacustrine environment. The third facies of sandy alternating beds of sand and mud is distributed around the Kaki and Oyachi areas. Cross laminations suggest that paleocurrent direction is from NE to SW(Tables 13 and 14). This facies is the deposits along coastal area of the lake. The gravels are composed of chert, sandstone, and "quartz porphyry"(Table 8). The last facies of sands and gravels is developed only at the eastern end of hills to the west of Yokkaichi. The composition of gravels is characterized by the presence of crystalline schist (Table 8).

Komeno Formation is distributed in the area to the north of Inabe, and is composed almost entirely of gravels. This sedimentary facies represents alluvial fan. The amount of gravels in the sediments decreases northward (Table 12), and according to Yokoyama (1969), the paleocurrent direction is from south to north (Fig. 39). The composition of gravels is dominated by chert and sandstone.

Table 12. Lithologic proportions of sediments of the Oizumi and Komeno Formations.

Locality	area	gravels	sand & gravel	sand	alt.	mud
Kariyagawa	B	68.6	-	4.3	1.3	25.8
Sushirodani	B	29.9	14.6	11.9	-	43.6
Uchiage	B	15.2	19.5	12.1	4.9	48.4
Higashidani	B	5.8	29.1	11.3	11.2	42.5
Kanae	B	-	5.6	39.7	7.9	46.9
Komeno	A	-.	6.8	43.3	13.1	36.8
Tashida R.	C	6.9	2.9	17.6	14.1	58.5
Nishikoyamadani	A	1.5	-	25.1	37.0	36.5
Higashikoyamadani	A	-	2.3	13.4	21.8	62.6
Akechi R.	A	-	-	3.8	34.0	62.3
Kuragari	A	-	2.4	32.9	16.2	48.6
Karegawa	A	2.2	1.4	37.8	7.8	50.7
Nukata	D	-	-	10.7	10.7	78.7
Kaki (W)	E	-	42.9	-	6.2	50.9
Kaki (E)	E	5.3	24.6	26.0	-	44.1
Heizu	E	12.8	15.1	7.5	7.7	56.9
Osawadai	E	-	30.9	4.3	9.0	55.8
Agata	E	-	51.9	13.4	10.5	24.1
Kawashima	F	-	7.2	30.5	27.4	35.0
Tomari	F	19.4	41.8	3.2	-	35.5

Locality	area	gravel	sand & gravel	sand	alt.	mud
Nishiyama	B	100	-	-	-	-
Komeno	B	75.2	-	-	6.1	18.7

Table 13. Paleocurrent direction deduced from cross laminations in Oyachi area.

Locality	Horizon	Mean direction of paleocurrent	Consistency ratio	Number	Average dip
Agata	Oizumi F.	153	99.0	5	34.2
Agata		99	99.8	5	30.3
Agata		236	99.8	6	33.8
Agata		80	99.5	5	23.6
Agata		248	99.6	5	24.3
Agata		274	99.8	5	30.8
Agata		166	99.8	7	31.7
Agata		178	99.6	6	21.4
Agata		165	99.8	5	25.3
Agata		162	98.3	6	27.8
Agata		206	99.9	5	24.5
Yamanoisshiki		228	99.7	8	34.7
Yamanoisshiki		184	99.8	7	38.0
Yamanoisshiki		185	99.9	6	37.3
Akatsukidai		187	99.8	5	22.2
Akatsukidai		168	99.9	3	31.7
Akatsukidai		181	99.4	4	23.0
Akatsukidai		154	99.9	4	31.0
Akatsukidai		171	99.6	8	34.8
Oyachi (S)		274	99.3	10	30.1
Oyachi (S)		218	99.7	10	34.3
Ikaruga		187	99.8	5	15.1
Ikaruga		175	99.8	5	25.8
Ikaruga		280	99.4	5	34.7
Tarusaka		165	99.2	5	22.9
Tarusaka (N)		250	99.4	10	26.7
Tarusaka (N)		186	99.3	5	26.0
Tarusaka (N)		204	99.8	6	27.5
Mitachi		33	99.5	4	28.8
Mitachi		286	99.8	5	27.4

Paleocurrent direction, that is, vector means are represented by anticlockwise angle from east direction.

Table 14. Paleocurrent direction deduced from cross laminations in the Yokkaichi and Kameyama areas.

Locality	Horizon	Mean direction of paleocurrent	Consistency ratio	Number	Average dip
Komono (E)	Oizumi F.	224	99.8	5	33.2
Komono (E)		177	99.8	5	28.8
Komono (E)		98	99.9	2	46.5
Sakura (W)		43	97.6	5	28.4
Sakura (W)		221	99.8	5	22.6
Sakuradai		169	99.8	8	27.6
Sakuradai		176	99.5	4	24.5
Kawashima (S)		120	99.4	6	26.1
Aobacho		193	99.6	5	31.5
Aobacho		173	98.8	5	30.4
Nishihino		195	99.4	4	31.0
Hagicho (W)		137	99.9	3	26.4
Sasagawacho (S)		154	99.8	5	30.1
Sasagawacho (S)		227	99.1	2	20.6
Sasagawacho (S)		265	99.7	3	28.1
Nishishonai	Kameyama F.	353	99.6	5	24.8
Iwahara		72	99.6	51	18.1

Paleocurrent direction, that is, vector means are represented by anticlockwise angle from east direction.

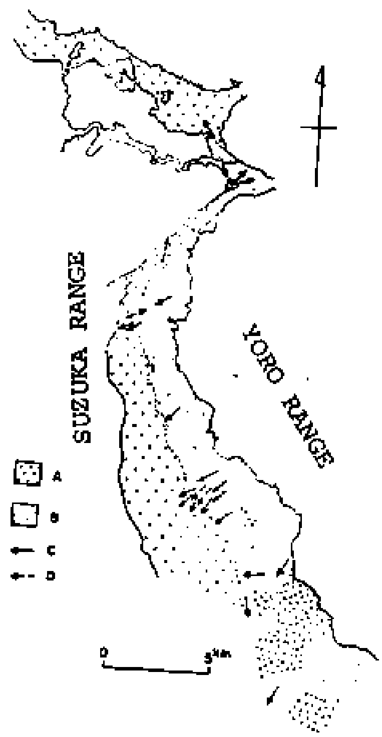


Fig. 39. Paleocurrent direction of the Tokai Group in the Tara area (after Yokoyama, 1969).

A: Komeno Formation, B: Oizumi, Ichinohara Formation,

C: mean directions of cross beddings,

D: mean directions of inclination of gravels.

The sediments assigned to Stage II around Kameyama is represented by the upper and middle Kameyama Formations and also by the Sakuramura Formation. In the middle Kameyama Formation, the basal part contains sand and gravel layers, but is composed mostly of alternating beds of mud and sand. It is lacustrine deposits. Cross laminations suggest that paleocurrent direction is from SW to NE (Yokoyama, 1969). The upper Kameyama Formation is composed of alternating beds of sand and mud, and is similar depositional environment to that of the underlying middle Kameyama Formation. The Sakuramura Formation is distributed in the area to the north of Kameyama City. As it is composed of alternating beds of gravel, mud and sand with large amount of lignite beds, then, it is shallow lacustrine deposits.

C. PALEOGEOGRAPHY OF THE SEDIMENTARY BASIN OF LAKE TOKAI

In this section, paleogeography of Lake Tokai at two stages; Stage I and Stage II will be discussed.

a. Stage I (ca 6.0 m.y. to 3.0 m.y.)

In the early Stage I, an alluvial plain environments was dominated in the area around Chita Peninsula and the Nanse area, in which gravelly sediments were deposited there. In the Nanse area, these gravels were supplied from west, while from east in the Chita Peninsula. The gravels deposited in the Nanse area contains rhyolitic welded tuff originated from the Koto Rhyolite area (Wada, 1982), and it is inferred that the water course of those days, the Koto-Kameyama water course of Kuwahara (1971), ran from the Koto area to the Kameyama area (Fig. 40-a). On the other hand, the presence of gravels originated from granite and Miocene sandstone of the Suzuka Mountains suggest that this area was not in depositional condition. The gravels deposited in the Chita Peninsula contain crystalline schist derived without doubt from the Sambagawa belt nearby, suggesting the water course from southeast to northwest.

Succedingly, a large water body of Lake Tokai appeared in the area extending from the Nanse area to the present Chita Peninsula. This lake was the ellipsoidal in shape with E-W elongation, and in Chita Peninsula, coarse materials were supplied from east. After then, northward development of the sedimentary basin took place in and an alluvial plain with gravelly sediments appeared in the area around Nagoya. Moreover, the lake continued in the southern area, where alternating beds of mud and sand were deposited (Fig. 40-b). In Chita Peninsula area, coarse materials were supplied from north.

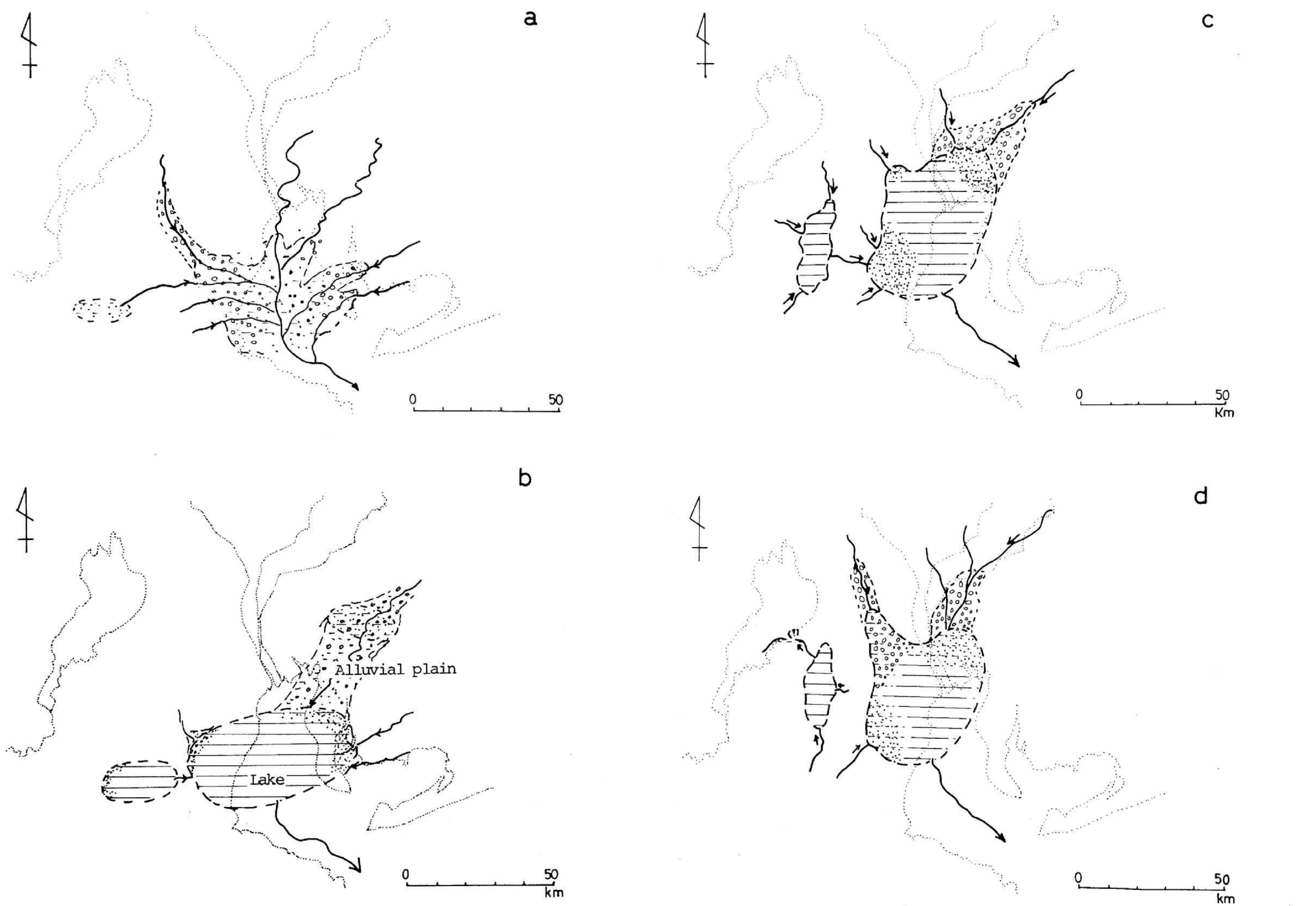


Fig. 40. Paleogeographic map of the sedimentary basin of Lake Tokai since Pliocene.

a : Depositional age of the Saigyodani Formation

b : Depositional age of the Kusuhara and Lower Kameyama Formations

c : Depositional age of the Kono Formation

d : Depositional age of the Lower Ichinohara Formation

b. Stage II (ca 3.0 m.y. to 1.2 m.y.)

Northwestery migration of the sedimentary basin of Lake Tokai underwent ca 3.0 m.y. B.P. Since that time, new sedimentary basin of Lake Tokai existed mainly in the Hokuse area and Ise Bay area (Fig. 41). In this section, transition of Lake Tokai during the Stage II will be described with each time interval (substage) defined by four volcanic ash layers (Ichinohara, Bando-1, Bando-2 and Pumice volcanic ash layers). Relationship between the lithology and those datum planes is shown in Fig. 42.

i). substage below the Ichinohara volcanic ash layer

The distribution of the sediments in this substage is known from the foothills of the Yoro Mountains to north of Kameyama, which are represented by gravels of the Biroku Formation, alternating beds of the Kono Formation, and alternating beds of sand and mud of the middle Kameyama Formation. In the northern part of the sedimentary basin, alluvial fans were developed locally at the foothill areas of the present Yoro and Suzuka Mountains which were yet in low-relief topography, but the supply of coarse materials was very rare except for the gravels of alluvial fans. In Inabe and its southern area, shallow lacustrine sediments were widely developed (Fig. 40-c). In the southernmost part of the sedimentary basin, coarse materials were supplied from the Suzuka Mountain area as a result of upheaving of the southern area.

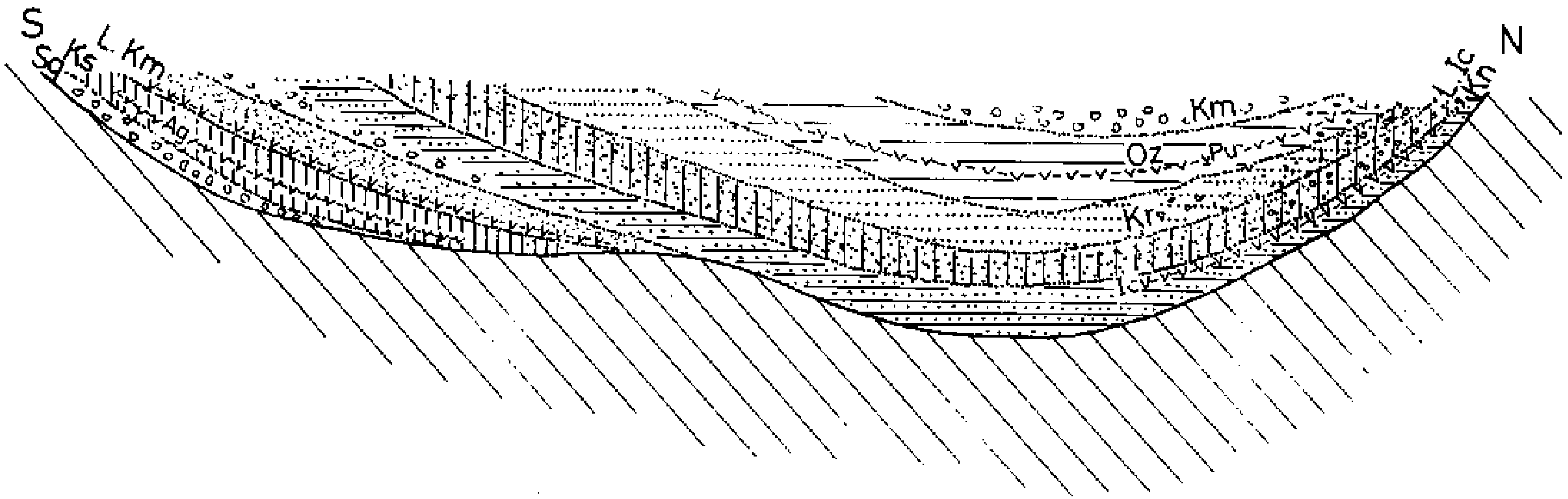


Fig. 41. Generalized geologic profile of the Tokai Group on the west coast of Ise Bay. (Sg: Saigyodani F., Ks: Kusuhara F., L. Km: Lower Kameyama F., Kn: Kono F., L. Ic: Lower Ichinohara F., Kr: Kuragari F., Oz: Oizumi F., Km: Komeno F., Ag: Akogi volcanic ash layer, Ic: Ichinohara volcanic ash layer Pu: Pumice volcanic ash layer)

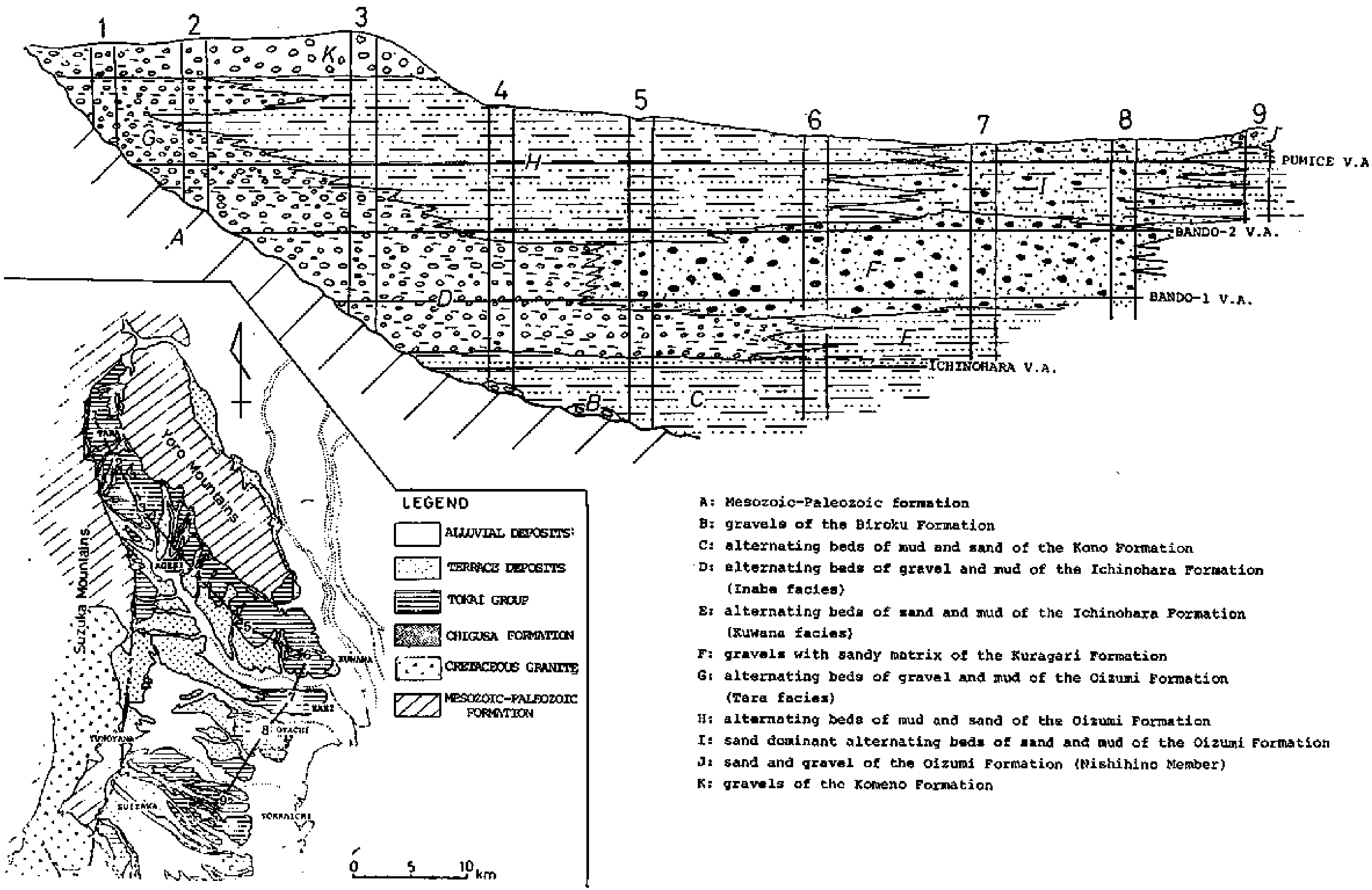


Fig. 42. Relationship between lithology and volcanic ash layer in the Hokuse area.

The areas of the Nanse, Nagoya and Chita Peninsula where the sedimentary basin of the Stage I almost was dried up.

ii). substage between the Ichinohara and the Bando-1 volcanic ash layer

This substage can be further subdivided into three phases. In the early phase, shallow lacustrine environment continued from the former substage, in which alternating beds of mud and sand were deposited.

The middle phase is represented by the deposition of alternating beds of gravel and mud (Inabe facies of the Ichinohara Formation), and alternating beds of sand and mud (Kuwana facies of the Ichinohara Formation). In the Inabe and Hokusei area, an alluvial plain was widely developed, where gravels were supplied from north, while lacustrine environment developed in the Kuwana area (Fig. 40-d).

The last phase is represented by deposition of alternating beds of gravel and mud (Inabe facies of the Ichinohara Formation), and sand and gravels (the Kuragari Formation). In the Inabe and Hokusei area, an alluvial plain was developed, where alternating beds of gravel and mud were deposited. It means that same environment as the middle phase was continued to this phase. In the Kuwana area, the water body existed precedingly was filled up by the materials supplied from northeastern area, and consequently, an alluvial plain with sand

and gravels was widely developed (Fig. 43-e). Those coarse materials were the first sediments which were supplied beyond the present Nohbi Plain area.

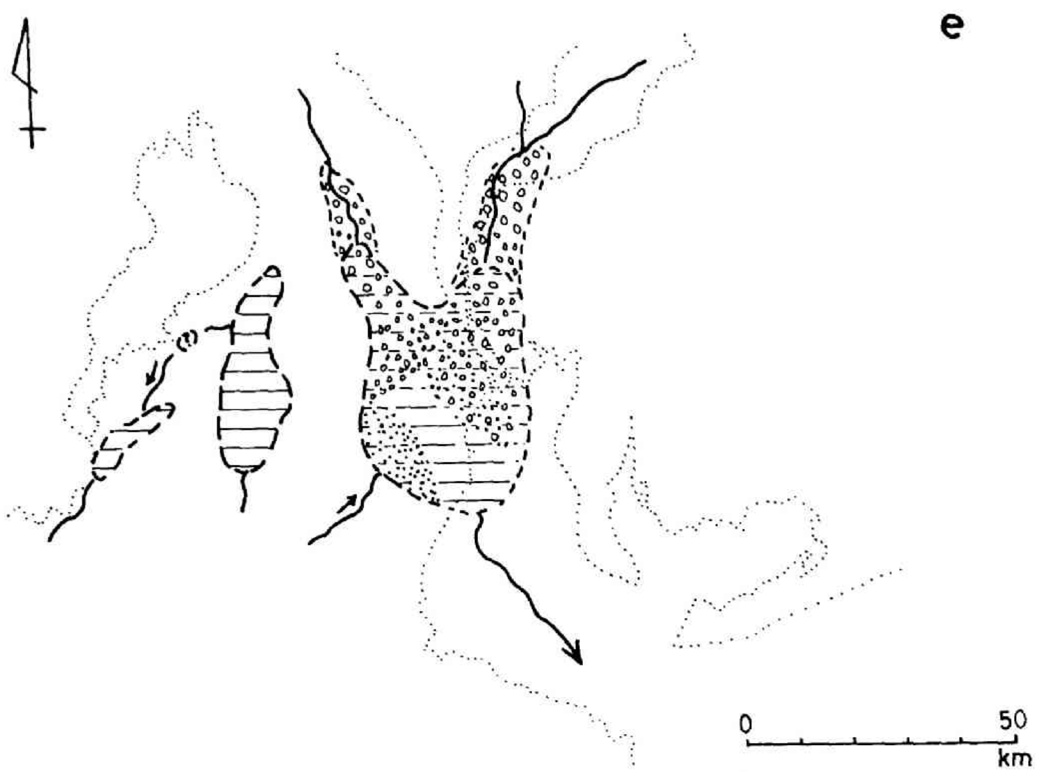
iii). substage between the Bando-1 and the Bando-2 volcanic ash layers

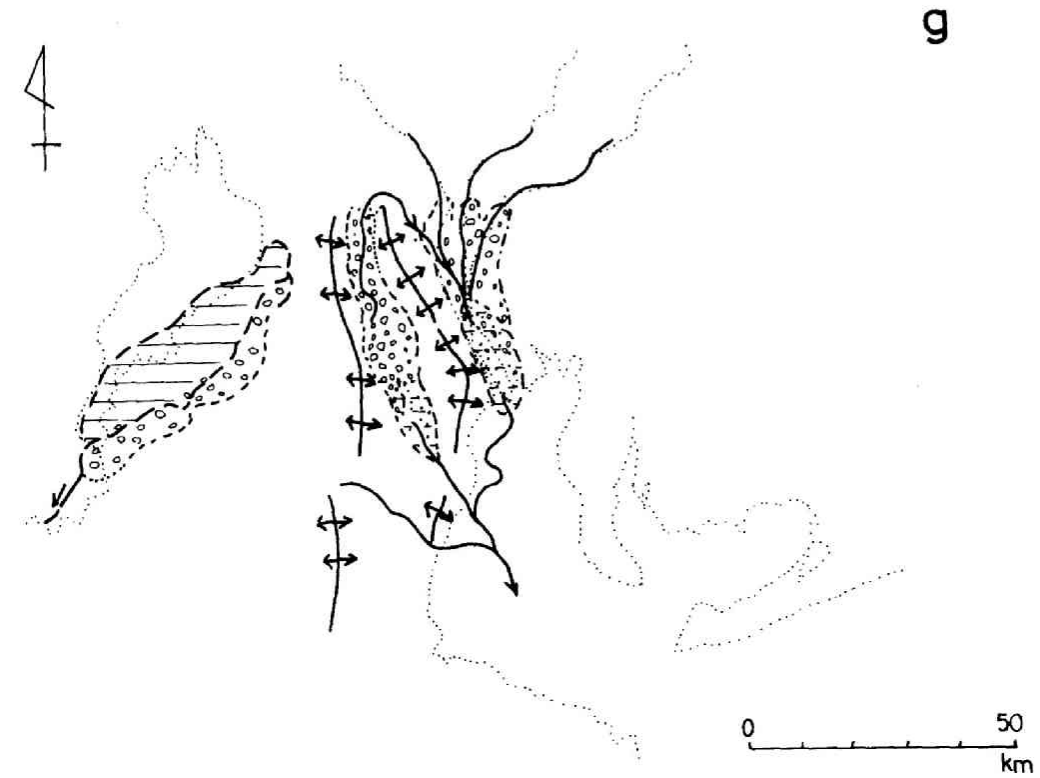
This substage is represented by the Inabe facies of the Ichinohara Formation and the Kuragari Formation. In the Inabe and Hokusei area, an alluvial plain was developed with supply of coarse materials from northern area. Alongside with this, in the Kuwana, Kaki and Oyachi areas, an alluvial plain was developed by the supply of coarse materials from eastern area. It indicates that same environment as the last phase of the former substage still existed.

iv). substage between the Bando-2 and the Pumice volcanic ash layers

This substage is represented by the alternating beds of gravel and mud (Tara facies of the Oizumi Formation), alternating beds of mud and sand (Oizumi Formation), and sandy alternating beds of sand and mud. Gravel supply from north was limited only to the Tara area.

In this way, an alluvial plain was developed in the Tara area. In the Inabe and Hokusei area, an alluvial plain condition was changed to lacustrine environment, and then alternating beds of mud and sand were deposited there. In the Oyachi and Kaki area, coarse material supply from east was further continued. In this substage, it is clear that the depositional field of coarse materials polarized gradually from north to south,





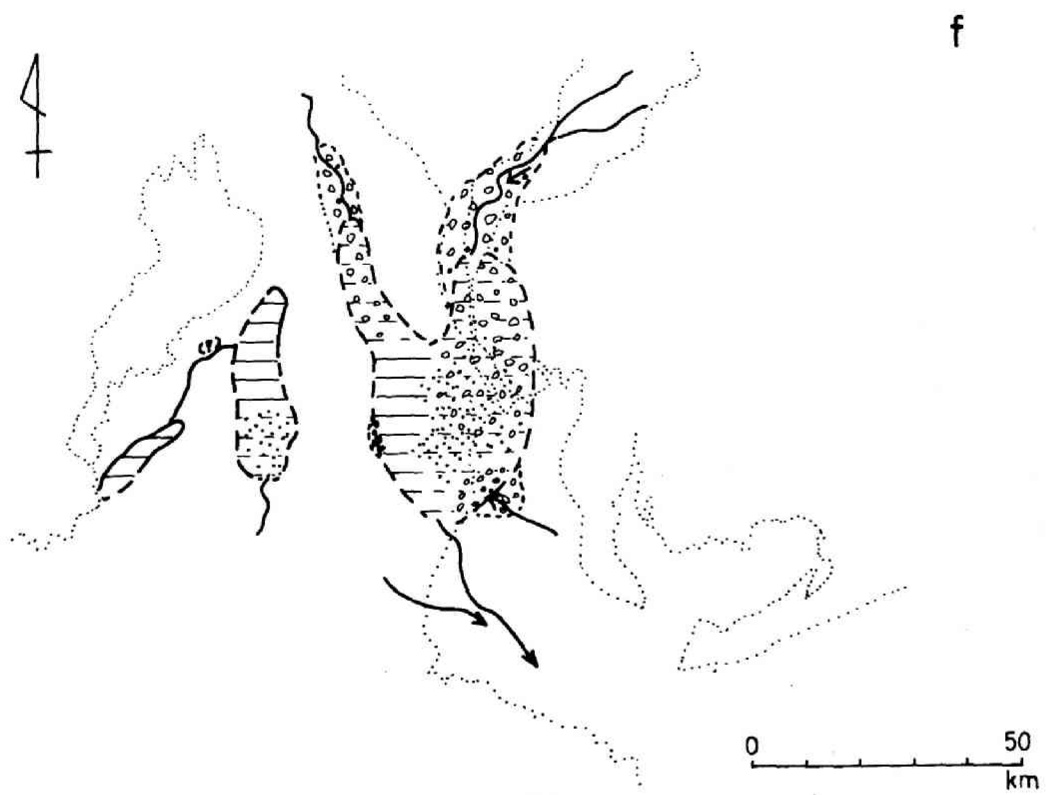


Fig. 43. Paleogeographic map of the Lake Tokai Sedimentary Basin since Pliocene.
e: depositional age of the Kuragari Formation f: depositional age of the Oizumi Formation g: depositional age of the Komeno Formation

and it may depend upon gradual uplift of the Kuwana Anticline area of the north.

v). substage between the Pumice volcanic ash layer and the base of the Komeno Formation

It seems that same environment as the former substage continued throughout Tara, Inabe, Kuwana, Kaki, Oyachi areas in this substage. Although an alluvial plain was developed in narrow belt in the Tara area, and lacustrine water body continued from Inabe to Kuwana area. In the Kaki and Oyachi area, an alluvial plain was developed by supply of coarse materials from northeast. Also, in the Yokkaichi area, an alluvial plain was developed by the gravel supply from east (Fig. 43-f).

vi). substage of the Komeno Formation deposition (Fig. 43-g).

This substage represents the last stage of sedimentary basin transition of Lake Tokai. In this substage, vast area of alluvial fan developed by filling up the sedimentary basin with gravels supplied from south. It may be influenced by rapid upheaval of the present Suzuka Mountain area. At the same time, topographic contrast became distinct by rapid upheaval of the present Yoro Mountain area and movement of the Kuwana Anticline.

D. TECTONISM AROUND ISE BAY SINCE PLIOCENE TO EARLY PLEISTOCENE

In this section, tectonic development around Ise Bay since Pliocene will be discussed taking the opinions of Kuwahara(1968) and Makinouchi(1976, 1979) into consideration.

Kuwahara(1968) discussed tectonism of the eastern area of Ise Bay (the area from the Nohbi Plain to Tono district including Kiso Mountains). He stated that this area had received tilting movement since Pliocene and this movement formed the topographic contrast between the sedimentary basin of Lake Tokai and eastern upheaving area. He called this tilting block as "Chubu Tilting Block". After the extinction of Lake Tokai, the sedimentary basin were differentiated and a tilting block ("Nohbi Tilting Block") was appeared in the area of the Nohbi Plain. This movement was called the "Sanage Movements". In addition, he recognized two types of tectonic movements, (Type-1 and Type-2), originated in crustal undulation of the Second Setouchi Depression. Type-1 is of long wave undulation which formed main depressional zone with parallel axis to the Setouchi trend. Type-2 is of short wave undulation crossing with the axis of the Setouchi trend, which made the alternating arrangement of basin and ridge in the depressional zone (Kuwahara, 1968).

Makinouchi (1976, 1979) paid much attention to the unconformable relation between the Tokoname Group (Tokai Group) and the Taketoyo Formation distributed at the Chita Peninsula. He distinguished two tectonic movements, one formed Lake Tokai and the other the Taketoyo Formation, respectively. He called the former the "Chita Movements" and correlated the latter to the "Sanage Movements".

As mentioned in the section of geologic structure, the sedimentary basin of Lake Tokai is divided into two subbasins by the Yoro-Ise Bay Faults. In other words, this tectonic line is the boundary between the Kinki and Chubu Blocks (Huzita, 1962). Therefore, the transition of the sedimentary basin of Lake Tokai has to examined in relation to the interaction between both tectonic blocks. The studies of Kuwahara (1968) and Makinouchi (1976, 1979) were based on the researches carried out in the Nagoya and the Chita Peninsula areas, both belonging to the Chubu Block. Moreover, as mentioned in the section of the correlation among the Tokai Group, the sediments in the later half of the geohistory of Lake Tokai (Stage II) is only distributed on the west coast of Ise Bay which belongs to the Kinki Block. Accordingly, the status of tectonic movement in the central and northern area of the west coast of Ise Bay has upmost importance in understanding of the tectonic development during the age of Lake Tokai. Tectonic developments in those areas during the age of Lake Tokai is summarized as follows(Fig. 44).

Before the appearence of the sedimentary basin of Lake Tokai, it is inferred that the area around Ise Bay was a low-relief topographic lowland which was resulted by the peneplanation in late Miocene (Kuwahara, 1968; Makinouchi, 1976, 1979). The geohistory of Lake Tokai in Stage I began with the deposition of a large amount of gravels in the southern area. It suggests that the topographic contrast between subsiding and upheaving areas appeared around this area. From the distribution of gravel facies, it is inferred that the elongated depressional zone developed at that time with axis parallel to the Setouchi trend, and successively, a large

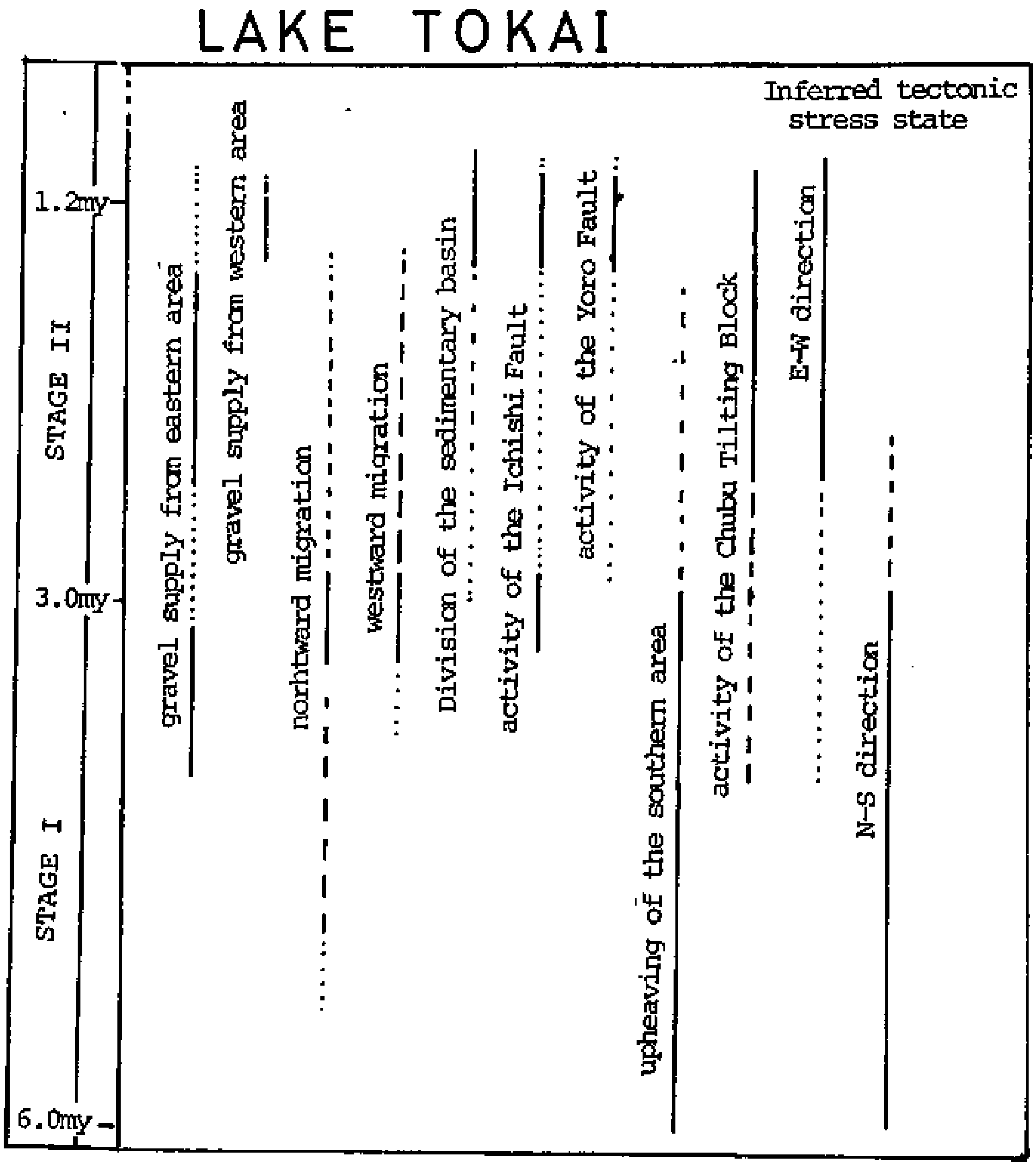


Fig. 44. Tectonic development around the sedimentary basin of Lake Tokai.

lake appeared in this depressional zone. This water body extended from Tsu to Chita Peninsula area, and was ellipsoidal with E-W elongation. The subsiding movement in this stage belonged to the tectonic movement of the Setouchi trend (Huzita, 1968), the tectonic stress being in N-S direction. In late Stage I, that depressional zone slightly shifted from south to north. It reflected the upheaving of southern sedimentary basin, and thus, the tectonic stress continued to be in N-S direction. In this stage, however, a large amount of gravels were supplied from east in the area around Nagoya, suggesting the tectonic movement of the Chubu Tilting Block.

To recapitulate, the tectonic movements of Stage I was assignable to the tectonism of the Setouchi trend with tectonic stress state in N-S direction, and that the Chubu Tilting Block joined to this tectonic movements in the later part of Stage I.

It was about 3.0 m.y. B.P. that the center of the sedimentary basin migrated further to the north. This migration was associated with rapid upheaving of the southern area of the sedimentary basin. Moreover, the area around Nagoya and of the Chita Peninsula were mostly dried up. It follows that the upheaving occurred also in the eastern area, Chubu Tilting Block. The large-scale migration of the sedimentary basin took place under the influence of rapid upheaving of the south and the Chubu Tilting Block of the east.

Differentiation of the sedimentary basin started through the migration process from Stage I to Stage II. The embryonic fault of Yoro separated the Kinki Block from the Chubu Block and both became to be influenced by different crustal movements.

In the early part of Stage II, muddy sediments abutted against the basement of Yoro Mountains. It is evident that the Yoro Mountains had already stood as a barrier in the sedimentary basin of Lake Tokai, but the area around the sedimentary basin were under low-relief topographic condition. Topographic contrast between depressional area and upheaving area became to be distinct step by step. Such contrast is represented by a large amount of gravel supply of that time. After then, the topographic contrast decreased as being represented as the upward fining cycle from the Ichinohara Formation to the Oizumi Formation. Through Stage II, the sedimentary basin migrated gradually northward with continuous upheaving of the southern area. Moreover, the tilting movement of the Chubu Tilting Block supplied a large amount of gravels of the Kuragari Formation from the east.
The Yoro Mountains and the Kuwana Anticline upheaved gradually. Consequently, the western sedimentary basin resulted to migrate to west under the influence of those tectonic activities. In the latest Stage II, it is clear that the Suzuka Mountains upheaved rapidly in N-S trend, and thus, the N-S structural trend became to be more conspicuous in the

western half of the sedimentary basin.

Summarizing above, the tectonic movements during Stage I was under the stress state in N-S direction and it formed the depressional zone with E-W trend, that is, the Setouchi trend. The Chubu Tilting Block joined with this movements. In Stage II, the tectonic stress state in E-W direction was represented mainly by the movement of the Chubu Tilting Block, but influence of that in N-S direction was conspicuous in the western half of Lake Tokai. Furthermore, such structure with N-S trend as being represented by the Suzuka Mountains became to be conspicuous(Fig. 44). Therefore, it has been recognized by those resolutions of tectonic history that the tectonism of the surrounding area of Lake Tokai should be analyzed from the viewpoint of the interaction between the upheaving of the southern area under the tectonic stress state in N-S direction and the tilting movement of the Chubu Tilting Block influenced by the tectonic stress state in E-W direction.

IV. SUBDIVISION OF THE SECOND SETOUCHI SUPERGROUP AND TECTONIC DEVELOPMENT

In the chapter III, the relation between transition of sedimentary basin of Lake Tokai and tectonism has been considered. Based on those results, the tectonism of Southwest Japan since Pliocene will be discussed here.

A. TECTONISM OF SOUTHWEST JAPAN SINCE PLIOCENE

The Rokko Movements was defined as all of the crustal movements occurred since Pliocene in the Setouchi Depression by Ikebe(1956, 1957). Itihara(1960) proposed the concept of the "Climax of Rokko Movements" in middle Pleistocene age before the formation of terrace deposits based on distinct difference of the structural features between the Osaka Group and the terrace deposits. Furthermore, Huzita(1962) distinguished two structural trends in this tectonic province, and Ikebe and Huzita(1966) redefined the Rokko Movements only to the crustal movement with meridional structural trend.

As for the tectonic movement around Ise Bay, Kuwahara (1968) proposed the concept of "Sanage Movements", and he pointed out that this movements is the same as the Rokko Movements. Therefore, these all belong to tectonic movements in Quaternary Period. On the other hand, Makinouchi(1979) recognized two types of tectonic movement since Pliocene from the studies on the sediments of the Chita Peninsula. According to him, among them, the younger movement was correlated to the Rokko Movements, while the older movement was newly defined as "Chita Movements". The latter implies 'the tectonic movement which caused Tokoname Group to deposit, deform and dislocate during the sedimentary process, mainly of Pliocene age' (Makinouchi, 1979).

The Quaternary tectonic stress state in this province has been discussed enthusiastically from the viewpoint of active faults distribution, geodesic survey and earthquake mechanism (Huzita, 1968, 1969; Huzita and Kishimoto, 1972; Huzita et al., 1973; Huzita and Ohta, 1977). Comprehensively, it has been deduced that stable tectonic compressional stress state with E-W trend governed all the area during that time. Recently, Huzita(1980) recognized two types of tectonic zone, one parallel to the Japan Trench and the other to Nankai Trough since the middle Pleistocene, and stated that they were compressed under the movements of the Pacific and Philippine Sea Plates. Directions of stress state since Miocene were established by dyke swarms method (Kobayashi, 1977, 1979; Takeuchi, 1980 and so on). As to that of Inner zone of Southwest Japan, the N-S compressional stress field was predominant during te Miocene and Pliocene Time (Kobayashi, 1977, 1979; bayashi and Nakamura, 1978). Therefore, Huzita's ea (1969) which suggested change of tectonic stress eld from N-S compressional state to E-W compressional ate is verified now. But, it remains to establish e detailed age and areal differences.

B. CORRELATION AMONG THE TOKAI, KOBIWAKO AND OSAKA GROUPS

As the main Plio-Pleistocene sequences in the Second etouchi Depression, Tokai, Kobiwako and Osaka Groups can be numerated (Fig. 1), Ishida and Yokoyama (1969) attempted ne correlation among those three groups tephrochrono- ogically, and succeedingly Ishida et al. (1969) reported agnetostratigraphy of the Plio-Pleistocene sequence n Kinki and Tokai districts and correlated with the ime scale of Cox and Dalrymple (1967). Thereafter, great deal of informations from paleomagnetism, fission rack ages and tephrochronology were accumulated. After eexamination of the results of Ishida et al. (1969), aenaka et al. (1977) proposed the magnetostratigraphy f the Plio-Pleistocene sequences in Kinki district.

The Kobiwako Group is developed mainly in Koto area outheastern part) and Kosei area (western part of Lake Biwa). ne stratigraphy of those deposits were summarized by Yokoyama : al. (1979) and Yokoyama (1981). Generally speaking, the upper part of this group (Katata Formation) is distributed in the Kosei area, while the lower part of the group (Iga-Aburahi, Sayama, Gamo and Yokaichi Formations in ascending order) is distributed in the Koto area.

In the Kosei area, a characteristic volcanic ash layer called the Azuki volcanic ash layer is intercalated in the lower part. The fission track age of this layer is 0.87 m.y. (Nishimura and Sasajima, 1970), and that of the Biotite volcanic ash layer which is about 20 m above the former is 0.70 m.y. (Nishimura and Yokoyama, 1975). Together with the detailed magnetostratigraphy done by Hayashida et al. (1976), it is possible to say that those sediments range from late Matuyama Reversed Epoch to early Brunhes Normal Epoch. The uppermost part of the group is composed of gravels (Ryuge sands and gravels).

Correlation among two core samples in and around Lake Biwa and the Kobiwako Group in the Kosei area was carried out tephrostratigraphically by Yokoyama (1975) and Takemura et al. (1976).

In the Koto area, magnetostratigraphy and fission track ages clarified that the Kobiwako Group in this area ranges from the Gilbert Reversed Epoch to the Matuyama Reversed Epoch (Maenaka et al., 1977; Tamura et al. 1977; Kobiwako Research Group, 1977; Hayashida and Yokoyama, 1979; Nishimura and Sasajima, 1970; Yokoyama et al., 1977a, 1980a). The uppermost part in the Koto area is composed of gravels (Yokaichi Formation).

In the Osaka Group around Osaka Bay, the upper part is characterized by alternating beds of marine and non-marine facies (Itihara and Kamei, 1970; Ishida, 1970). The initiation of such an alternation was about 1.2 m.y. B.P.(Yokoyama, 1979).

To the contrary, the lower part of the Osaka Group is characterized mainly by lacustrine and fluvial sediments, and the upper and lower parts are unconformable (Yokoyama et al., 1977b; Yokoyama et al., 1980c; Iida, 1980). Its lower part ranges from the Gauss Normal to the early Matuyama Reversed Epoch (Nishimura and Sasajima, 1970; Yokoyama, 1979; Iida, 1980; Maenaka et al.,1977; Torii et al., 1975; Yokoyama and Hayashida, 1980). The correlation among Tokai, Kobiwako and Osaka Groups may be shown as proposed in Fig. 45.

As stated precedingly, the sedimentary basin of Lake Tokai appeared at about 6.0 m.y. B.P. and shifted its place to northwest on a large-scale in about 3.0 m.y. B.P., and ceased its existence at about 1.2 m.y. B.P. From the viewpoint of distribution pattern of the sediments and the age of their deposition, the geohistory of Lake Tokai can be divided into two stages, Stage I from 6.0 m.y. B.P. to 3.0 m.y. B.P. and Stage II from 3.0 m.y. B.P. to 1.2 m.y. B.P.

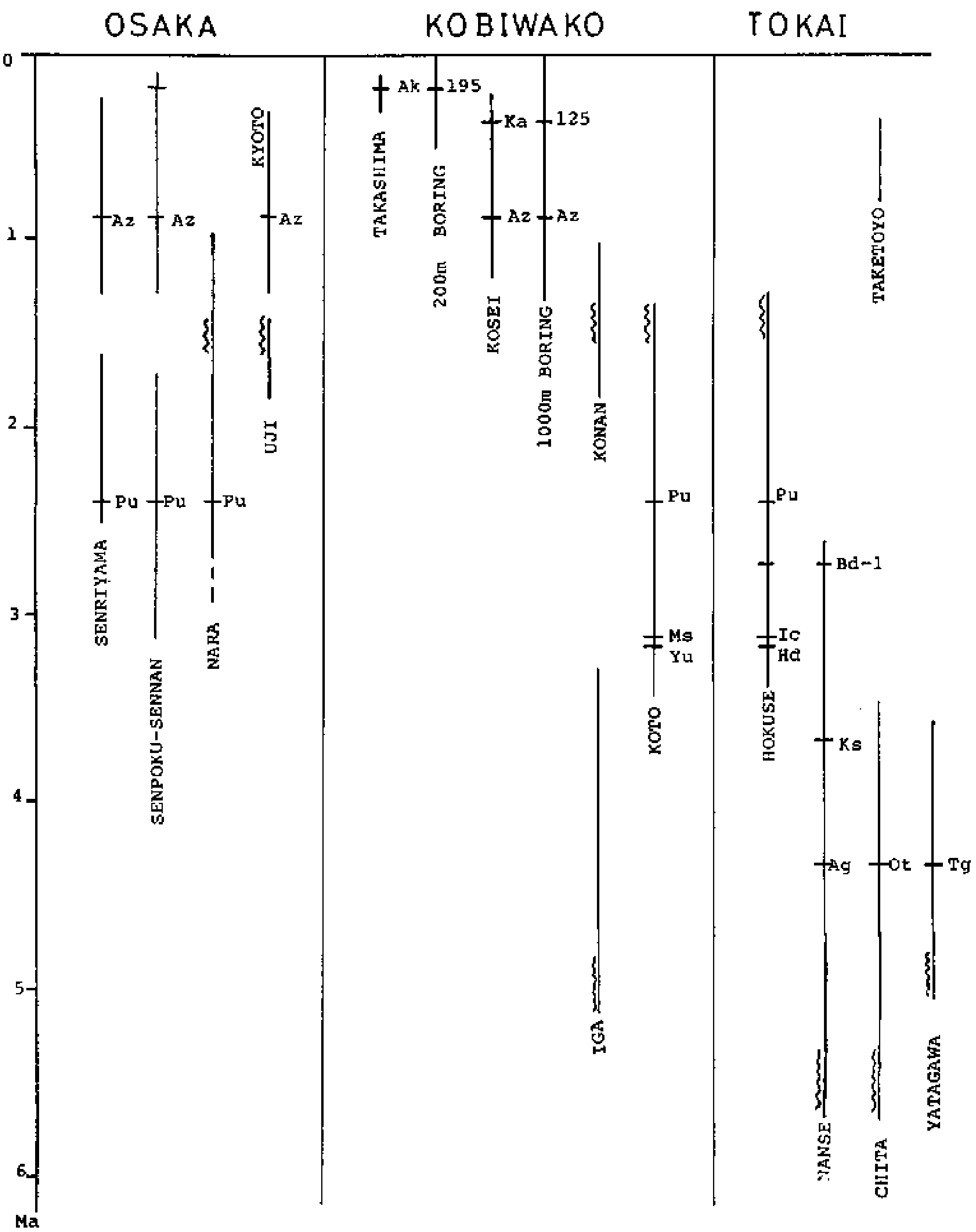


Fig. 45. Correlation chart among the Tokai, Kobiwako and Osaka Groups.

The sedimentary basin of Paleo-lake Biwa appeared at about 5-6 m.y. B.P. and shifted its place on a large-scale to north from Iga Basin to Ohmi Basin at about 3.0 m.y. B.P. After the disappearance of the water body in the Koto area, the center of the lake basin migrated to northwest at about 1.2 m.y. B.P.

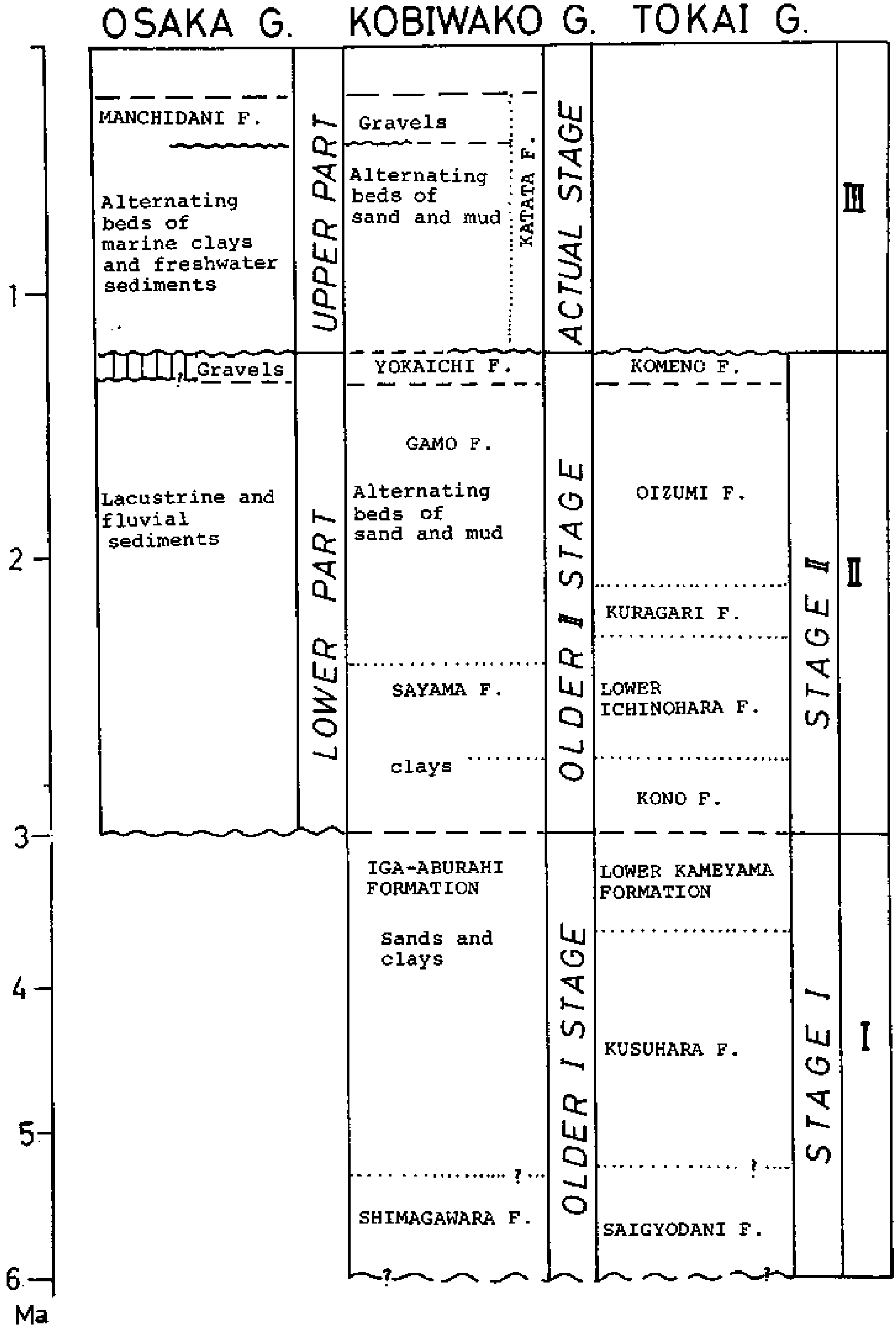
Further west, the sedimentary basin around the Osaka Bay appeared at about 3.0 m.y. B.P., but alternating beds of marine and non-marine sediments began to cover the lower part of the Osaka Group unconformably at about 1.2 m.y. B.P.

It follows that important episodes of the geohistory are in common among those three sedimentary basins; of about 3.0 m.y. and of about 1.2 m.y. B.P., respectively (Table 15).

C. COMPARISON OF SEDIMENTARY BASIN TRANSITION BETWEEN PALEO-LAKE BIWA AND LAKE TOKAI

It has been known that the geohistory of the Second Setouchi Supergroup can be subdivided by tectonosedimentary facies of about 3.0 m.y. B.P. and 1.2 m.y. B.P. This suggests that the change of tectonic stress state of this province took place simultaneously throughout three sedimentary basins. In this section, to compare the geohistory of Lake Tokai with that of Paleo-lake Biwa, patterns of sedimentary basin transition will be discussed.

Table 15. Subdivision of the Second Setouchi Supergroup.



According to Yokoyama (1969, 1981), the geohistory of Paleo-lake Biwa is divided into four stages: Older I, Older II, Actual I and Actual II stages. At first, Paleo-lake Biwa appeared in the Iga basin and clay dominant sediments were deposited in this water body ("Iga-ko") (Yokoyama et al., 1980a) (Older I stage). In the second, the center of the sedimentary basin shifted its place to north from the Iga basin to the Ohmi Basin, forming stable water body ("Sayama-ko") with massive clay deposition. The northward shifting of the sedimentary basin was inherited (Older II stage). During the time from Older II stage to Actual I stage, the center of the sedimentary basin migrated to northwest on a large-scale, and the gravels of the Yokaichi Formation represents the last sediments of Older II stage. The sedimentary basin of Actual I stage shifted its place gradually to west, accompanied by the upheaval of the eastern mountain area. This explanation was supported by the results of lithology, paleocurrent, sedimentological studies on the deposits of the Kosei area and those of the 1,000 m drilling cores at the rivermouth of the Yasu river (Yokoyama, 1979; Takemura et al.,1979). The gravels of the uppermost part of the Kobiwako Group in the Kosei area is the sediments of the last Actual I stage. These gravels was the first sediments supplied from the present western Hira Mountains. Followingly, the crustal movements along the Katata Fault became more active, and, after then, in Actual II stage, the area of the actual Hokko (northern lake) basin of the present Lake Biwa began to subside rapidly.

Therefore, the similarities deduced from the process of those two sedimentary basin transition are summarized as follows:

i). In early stage, the sedimentary basin appeared in southern area of the basin, and migrated gradually to north.

ii). Succeedingly, the sedimentary basin migrated to northwest on a large-scale.

iii).The sedimentary basin migrated gradually to west, and at last, it is divided by the structural movements in N-S trend accompanied rapid subsidence of the eastern area.

In this way, similar pattern of transition can be recognized in both sedimentary basins of Paleo-lake Biwa and Lake Tokai. But, large-scale northwestward migration was heterochronous, that is, about 3.0 m.y. B.P. in Lake Tokai, and about 1.2 m.y. B.P. in Paleo-lake Biwa.

D. TECTONISM AND BASIN MIGRATION

As mentioned before, the geohistory of the Second Setouchi Province had two conspicuous episodes of ca 3.0 m.y.B.P. and of ca 1.2 m.y. B.P. and a similar pattern of basin transition was revealed as recognized in both sedimentary basins of Lake Tokai and Paelo-lake Biwa. This suggests that the changes of the tectonic stress state were common throughout that province.

The sedimentary basins before ca 3.0 m.y.B.P.(Stage I of

Lake Tokai and Older I stage of Paleo-lake Biwa) are mainly characterized by E-W arrangement of depressional zone and their northward migration. It may owe to the upheaval of the southern area under the tectonic stress state in N-S direction. But, in the middle of Stage I, Lake Tokai received a large amount of gravel supple from the east which related to the movements of the Chubu Tilting Block. It suggested the beginning of new structural control which superposed the older one.

At the time of ca 3.0 m.y.B.P., the sedimentary basin of Lake Tokai migrated northwest.

After that time, the sedimentary basin of Lake Tokai migrated to the west as a whole, though slightly northward, by active movement of the Chubu Tilting Block under the stress state of E-W trend. But, in the same time interval, the sedimentary basin of Paleo-lake Biwa was migrating gradualy northward by the upheaval of southern area.

At the time of ca 1.2 m.y. B.P., the sedimentary basin of Lake Tokai became to extinct being accompanied with the upheaving of the Suzuka and Yoro Mountains with N-S structural trend. It was peculiar that the sedimentary basin of Paleo-lake Biwa transfered its position to northwest. After then, it migrated gradually westward by tilting of eastern area. This fact means the origination of conspicuous movement under E-W tectonic stress in the Ohmi Basin.

In this way, the sedimentary basin migration in Lake Tokai and Paleo-lake Biwa is commonly explained by the hypothesis of interaction between upheaving of the southern area and tilting of the eastern area (Fig. 46).

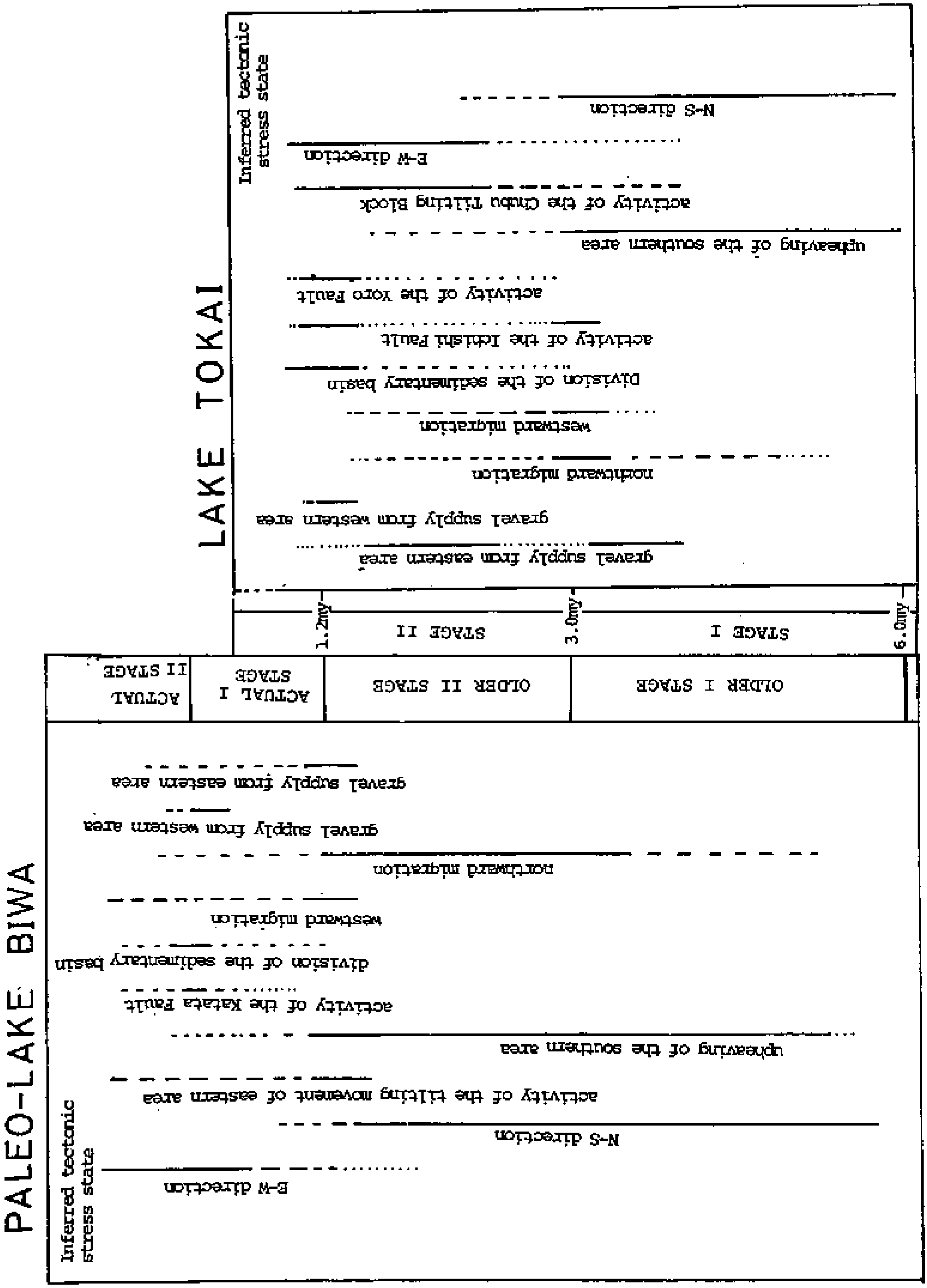


Fig. 46. Comparison of the tectonic development between the sedimentary basin of Lake Tokai and the Paleo-Lake Biwa.

Conclusively, the author proposed an idea that the deposition of the Second Setouchi Supergroup since Pliocene was under the influence of superposed two tectonic stress states which are represented by upheaving of the southern area and tilting of the eastern area. Hitherto, Huzita (1969) and others have stated that the tectonic stress state change since Miocene took place in the Inner zone of southwest Japan during the time of Pliocene and Pleistocene. This change from N-S compressional stress state to E-W one was conspicuous. Therefore, the result of the present work is not contradictory to that idea and confirms chronological setting and detailed process of tectonosedimentary turnover since Pliocene.

V. SUMMARY

1. The Plio-Pleistocene Tokai Group of the west coast of Ise Bay consists mainly of sands, muds and gravels in fluvial and lacustrine origin, and contains numerous volcanic ash layers and lignite beds. The stratigraphy of the Tokai Group in the Hokuse area (northern part of the west coast of Ise Bay) is summarized as shown in Table 2. On the basis of tephro-stratigraphy, lateral facies changes of those deposits were described precisely (Fig. 25).
2. On the basis of tephrostratigraphy, biostratigraphy, paleo-magnetism and fission-track ages, the Tokai Group in the Hokuse area was clarified to have the range from the Kaena event of the Gauss Normal Polarity Epoch to early Matuyama Reversed Polarity Epoch (about 3.0 m.y. B.P. to 1.2 m.y. B.P.) (Fig. 28).
3. In geologic structure on the west coast of Ise Bay, three conspicuous tectonic trends (Setouchi, Suzuka and Yoro trends) are discriminated (Fig. 30). The Tokai Group in the Hokuse area forms a basin structure.
4. The correlation among the sediments of the Tokai Group in various areas (west coast of Ise Bay, Chita Peninsula and area around Nagoya) was carried out precisely (Fig. 33). Consequently, it becomes to be clear that the geohistory of the sedimentary basin of Lake Tokai can be subdivided into two stages, Stage I (about 6.0 m.y. B.P. to 3.0 m.y. B.P.) and Stage II (about 3.0 m.y. B.P. to 1.2 m.y. B.P.).

5. In order to make sure the paleogeography of Lake Tokai, sedimentological data (lithology, lithologic proportion, gravel composition, paleocurrent directions and sedimentary facies) were described. On the basis of chronostratigraphy and those sedimentological data, the paleogeography of Lake Tokai was reconstructed (Figs. 40 & 43). Furthermore, the process of the sedimentary basin transition was examined from those paleogeographical researches. They are summarized as follows: After wide distribution of alluvial plains in early Stage I, a large water body appeared in southern area of the basin, which extends from Tsu area to the actual Chita Peninsula. Succeedingly, though, in the area around Nagoya of the north, the gravels were supplied from the eastern area and the alluvial plain was developed widely, the water body preexisted still remained in the southern area.

At about 3.0 m.y. B.P., in accordance with the northward shifting of the sedimentary basin which covered the area from Nanse to the Chita Peninsula, and the stable water body became to appear in the Hokuse area. After that, sedimentary basin was more developed northwardly, but, as the gravels supplied from the northern area were accumulated there, an alluvial plain was formed accompanied with a water body around Kuwana area. Subsequently, the gravels supplied from the eastern area reached to the present west coast of Ise Bay beyond the present Nohbi Plain, and filled the water body of the former age. Thus, the water body reduced its extent and was remained only in southwestern area. Followingly, as coarse materials from the northern area decrease in supply, water body was developed to north. In the last, large amount of gravels from the southwestern area (Suzuka Mountains) filled up that sedimentary basin and Lake Tokai attained to its terminal stage.

6. In connection with the mode of sedimentary basin transition, the tectonic development around Ise Bay was discussed. The tectonic development of surrounding areas should be considered from the interaction between the upheaving of the southern area under tectonic stress state of N-S direction and the movement of the Chubu Tilting Block influenced by the tectonic stress state of E-W direction.
7. By tephrostratigraphy, magnetostratigraphy and fission track ages, the correlation among the Tokai, Kobiwako and Osaka Groups was made (Fig. 45). Consequently, it becomes clear that the boundary of Stage I and Stage II of Lake Tokai (about 3.0 m.y. B.P.) is fairly coincidental with the boundary of Older I and Older II stages of Paleo-lake Biwa, and also with the initial stage of the sedimentary basin around the Osaka Bay. This boundary should be regraded to have important role in the geohistory of the Second Setouchi Inland Depression. Moreover, it is very curious that the extinction of Lake Tokai (about 1.2 m.y. B.P.) was correlated with the boundary between Older stage and Actual stage of Paleo-lake Biwa, and also with the first appearance of alternating beds of marine and non-marine deposition around the Osaka Bay.
8. To compare Lake Tokai with Paleo-lake Biwa, similar migration

pattern of the sedimentary basin was recognized. But a large-scale migration of Paleo-lake Biwa to northwest occurred later than that of Lake Tokai.

9. Similar migration pattern of two sedimentary basins (Paleo-lake Biwa and Lake Tokai) were examined as the results of mutual interaction between the southern area upheaving and the tilting movement of the eastern area. Before a large-scale northwestward migration of the basin, tectonic stress state was under N-S compression, but it changes to E-W compression after the migration. These results obtained from the tectonosedimentary analysis are concordant with the results deduced from the analytical studies of dyke swarms, active faults, earthquake mechanism and so on. This change of stress field seems to be delayed in western area. These two tectonic stresses discussed here may correspond to two types of Quaternary tectonic zone proposed by Huzita (1980).

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